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REVIEW OF UNDERWATER ACOUSTIC SYSTEMS AND METHODS FOR LOCATING OBJECTS LOST AT SEA

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1.0 INTRODUCTION

The Langley Research Center (LaRC) has been conducting a study to provide information and recommendations pertaining to the security and eventual recovery of aircraft or objects being transported by aircraft and lost at sea.

This work was sponsored by the United States Air Force Weapons Laboratory, Kirtland, AFB, New Mexico, in support of their Attachable Components to Enhance Security (ACES) program.

The approach taken by Langley was to partition the total problem into a search and locate operation and a recovery operation. The potential recovery of an object depends, among other things, upon establishing the precise location of the object. Precise location methods require accurate estimates of the boundaries to a search area. This report will first outline existing methods having potential for defining a search area, and will then review current instrumentation technology for precisely locating lost objects. An "interim" location method using current technology will be suggested, and a system concept for an "advanced" location technique will be presented. The instrumentation research and development required to implement the advanced technique will be identified. The organizations, methods, hardware and constraints currently involved in an open ocean recovery operation will also be reviewed.

2.0 DEFINING THE SEARCH AREA

It is of fundamental importance to establish a means of estimating the search area boundaries surrounding the lost object. These boundaries

define the area within which a high probability exists for successfully locating the object. Given an underwater acoustic location device attached to the lost object, knowing these boundaries and the location system characteristics would allow a search plan to be formulated and implemented.

There are several existing methods with potential for identifying a search area, even though most have considerable disadvantages. These methods will be reviewed here; however, definition of a completely satisfactory method was beyond the scope of this study and none will be proposed. Again, it is assumed that the object is being transported over the ocean via aircraft.

2.1 Voice Communications

This involves determining the aircraft location periodically using Omega or some other navigation system and relay location via low freqency radio receiving station. The data can be coded for security. The volume of data would be low and the resulting search area would be large.

2.2 Radar Tracking

This implies use of a coded transponder on the aircraft in conjunction with a combination of land-based and airborne surveillance radars, along with radar picket ships to constantly monitor the aircraft's location. This method can be expensive and might interfere with operational military forces.

2.3 Search and Rescue System

The Search and Rescue Satellite (SAR) and land-based SAR facilities are available to establish an impact location. This can be done by

mounting a commercially available Emergency Position Indicating Radio Beacon (EPIRB) on the aircraft such that the EPIRB would detach on impact and float free (figure 1). The beacon would be water activated and would continue transmitting until the battery expired. The position is determined by a tracking satellite network which can locate the impact area within 10 miles. One current disadvantage is that as much as 6 hours can pass before satellite reception causing an error in determining the impact point due to the drifting position of the EPIRB.

It may be possible to eliminate this deficiency using a second generation EPIRB, which is expected to be operational in the near future. The signal transmitted from this beacon contains information that identifies the vehicle, and the digital data format includes blank space that could accommodate impact position information. The beacon would have to be modified to interface with the aircraft's navigation system to allow positional data to be periodically updated. The last position stored in memory would identify the impact point.

Security may be a disadvantage here since the SAR satellite network is a multinational operation. The NASA contract for SAR responsibility is Mr. Burnie Trudell, Goddard Space Flight Center, Greenbelt, MD 20771.

2.4 Subsurface Sound

This method employs a US Navy system which includes an explosive underwater sound signaling device and an array of subsurface listening stations located around the world's oceans. The signaling devices (type MK 59 mod 5) are suitable for aircraft mounting and are designed to detonate in the "deep

sound channel" at depths greater than 1,000 feet (reference 1). (See figure 2.) The reported system accuracy is 15 miles over a range of thousands of miles.* The disadvantage is that their performance is restricted to transmission in the "deep sound channel" which eliminates much of the continental shelf area of the Atlantic Ocean and most of the Mediterranean Sea as well.

2.5 Satellite Tracking

Another system with potential for defining the search area is the Tracking and Data Relay Satellite System (TDRSS) described in reference 2. TDRSS east will be in geosynchronous orbit at 0° N to 41° W, and will cover the Atlantic and the Mediterranean Sea (figure 3).

Aircraft tracking from space was not an intended application for TDRSS; however, it seems to be feasible. The tracking mode is expected to be a relatively high demand TDRSS service and dedicated support for an Atlantic crossing may be difficult to schedule. An alternate approach might be for the aircraft to uplink its navigation data through one of the TDRSS communications channels, with the satellite relaying the data to the TDRSS control center in White Sands, New Mexico. Either the tracking or telemetry link approach seem technically attractive. The low data rate requirement makes this application particularly compatible with TDRSS, and the high precision requirement for estimating impact location offers a distinct advantage. Possible disadvantages are scheduling difficulties for the

*Private communications, Yancey McGann, Naval Weapons Station, Yorktown, VA.

tracking service and the additional aircraft instrumentation required for either tracking or communications. The NASA contact is the User Planning Coordinator, Mr. Edwin Low, Code 804.3, Goddard Space Flight Center, Greenbelt, MD 20771.

3.0 UNDERWATER LOCATION AID SYSTEMS CONSIDERATIONS

The most time consuming part of a successful ocean recovery operation may be finding the exact location of the object that has been lost. A satisfactory system must detect the lost object and provide data to "home-in" on the position that may be hundreds or even thousands of meters below the surface. One of the most effective aids in locating an object lost in the ocean is the use of underwater acoustics. An active sound transmitter or transponder used in conjunction with a compatible sound receiver forms a detection system that yields reasonable range and positive identification of a lost object. Using this type of system requires that the underwater acoustic device be attached to an object before being transported. If jettisoned or lost in the ocean, the active transmitter will substantially enhance the detectability of the lost object. Using receivers with suitable signal processing aboard search craft, data can be provided to accurately pinpoint a position on the ocean floor.

Before selecting an acoustic system for a particular underwater location aid application, the following key items must be considered:

- Size
- Environment
- Lifetime
- Security
- Acoustic performance

The transmitter and receiver must be considered separately.

The transmitter size must be compatible with the size and installation method of the object and with the acoustic range requirement. For security reasons, it should be activated only when a search craft is present. Two straightforward approaches to accomplish this are by using a time-delayed turnon that anticipates the arrival time of the search craft or by direct interrogation by the search craft upon arrival. The transmitter must survive high shock loads due to impact and high temperatures from possible explosive fires within an aircraft. It must then operate under pressure in the deep ocean. The signal characteristics should be compatible with existing potential search equipment and should provide as much range as possible for as long as possible.

Portability must be considered with respect to the receiving system. The advantage in a portable system is that it could be used from a variety of search platforms or from ships of opportunity. The receiving equipment must withstand only the usual environmental problems associated with operating in the sea aboard ships or helicopters for extended periods of time.

The subsurface hydrophone must be designed for minimal "self-noise" while being towed in heavy seas, and the signal processor must provide range, directional and depth information in real time.

The environmental, range, and lifetime considerations for transmitters deserve more quantitative discussion.

3.1 Environmental

In order to estimate the environmental conditioning, a scenario leading to the object being lost at sea must be posed. As examples, two situations will be described here. Given an aircraft transporting objects fitted with

acoustic transmitters, the mission could be aborted with the aircraft falling relatively intact into the sea at an angle greater than 45°. This could produce a shock in excess of 300 g, over 0.2 sec, upon entry (reference 3), or the aircraft might explode producing a 10,000 g pyrotechnic shock and a fireball lasting several seconds with a heating potential of more than 400 btu/sq ft/sec. In this situation, the object could separate from the vehicle and free fall into the ocean with an entry impact, again, approaching 10,000 g (reference 4). In this case, both the pyrotechnic and impact shocks are less than 0.1 msec in duration, and the magnitude of the latter could vary approximately an order to magnitude depending upon the mass and shape of the object. These estimates should be considered worst case figures. Finally, the object would experience a thermal shock entering the water.

3.2 Range

Several important factors affect the operational range of an underwater acoustic transmitter. Size and weight restrictions, depth requirements, and the signal spectral characteristics are transmitter-related items. The directivity, sensitivity, and noise characteristics of the receiver, along with the noise associated with sea state and the search platform, are other important factors. A set of assumptions concerning the magnitude of these performance parameters and requirements will be made here in order to specify a minimum transmitter output power for a location operation in 20,000 feet of water. This is the maximum expected depth for recovering objects based on the planned capability of the Navy's modified Sea Cliff deep submersible. This capability would cover most of the Atlantic and Mediterranean as shown in figure 4. The search craft is assumed to carry a down-looking sonar with a

30° beamwidth (3 dB points), and the transmitter is radiating omnidirectionally. With a 30° field-of-view, the footprint diameter d (figure 5) is

$$\begin{aligned} d &= 2(6100) \tan 15^{\circ} \\ &= 3269 \text{ meters} \\ &= 2.03 \text{ miles at } 20{,}000 \text{ ft depth} \end{aligned}$$

The appropriate sonar equation required in computing the minimum acoustic output source level is (reference 5)

$$TL = 20 \log_{10} R + \alpha R$$

where

TL = transmission loss, ocean floor to surface, dB referred to 1 dyne/cm^2

R = range or depth in meters

α = spectral related absorption = 1 dB/km at 10 kHz

This leads to

$$\begin{aligned} TL &= 20 \log_{10} 6{,}300 + 10^{-3} \times 6{,}300 \\ &= 82 \text{ dB} \end{aligned}$$

The minimum transmitted source level required for detection at the surface is given by

$$SL = TL + N + 10 \log_{10} W - DI + SNR$$

N = ocean noise level at sea state 6 and ship speed of 15 knots
= -40 dB

W = receiver bandwidth, 500 Hz

DI = receiving transducer directivity index, 16 dB

SNR = input signal-to-noise ratio at receiving transducer, 10 dB

are reasonable assumptions. In this case the required transmitter output is

$$SL = 83 - 40 + 27 - 16 + 10$$
$$= 64 \text{ dB (referenced to 1 dyne/cm}^2\text{)}$$

This represents a typical minimum output requirement for an attachable 10 kHz acoustic source.*

3.3 Lifetime

The lifetime of operation within specification for an underwater acoustic transmitter involves design tradeoffs between weight and output power. The allowable size and weight are largely dependent upon the physical characteristics of the object, the attachment method, and the carrier. The travel time to the search area, the size of the search area, and the density of coverage during the search affect the lifetime requirement for the transmitter. A transmitter designed to operate in a low power, standby mode until interrogation from a search craft would minimize the time spent in the higher power transmit mode and therefore maximize lifetime.

In order to estimate the minimum operating lifetime required for an underwater location aid, the following example will be posed. Consider a transport aircraft traveling at 300 knots on a predefined course and reporting its position at half hour intervals. Given an accident, the impact point

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*These output requirements represent idealized operating conditions. Attachment to objects or incapsulation inside a transport vessel may modify the acoustic radiation pattern of the source (reference 6).

would be known to within approximately 180 miles along its planned course. The width of the 180 mile swath would be 5 miles based on an estimated 2.5-mile accuracy for determining position from a standard Omega measurement. The search area would then be 900 square miles. A single search craft with an average speed of 14 knots could cover this area in approximately 26 hours with a water depth of 20,000 feet and 52 hours when the depth is 10,000 feet. A 50 percent overlap in sensor footprint to allow for realistic imprecision in navigation over the search area is recommended. In this case, it would take more than 100 hours for a once over search of this area if the depth were 10,000 feet or less. A minimum operating lifetime of 100 hours for the underwater location aid would be required.

4.0 AN INTERIM SYSTEMS APPROACH

In this section, a location aid system composed of existing hardware and requiring minimal upgrading will be suggested. The required design modifications will be outlined, along with both hardware and operational deficiencies to be addressed by a future systems approach. Recovery is an integral part of the total systems problem; therefore, current recovery alternatives will be discussed.

4.1 Location

An interim location system may be based upon the following discussion of baseline requirements, existing hardware, existing methods, and recommendations for upgrading.

4.1.1 Baseline Requirements

The receiver and transmitter performance characteristics assumed or derived in the previous section constitute the baseline requirements for an

interim system. Location in the open ocean in up to 20,000 feet of water is a requirement, but the shallower near shore situation will also be discussed.

4.1.2 Existing Systems

Compatibility with the largest number of search platforms is a prerequisite for the transmitter. A survey was conducted, considering both naval and civilian vessels, to determine the spectral and modulation characteristics that would best meet this condition. Most surface ships have sonar systems onboard that operate in the 9 to 12 kHz frequency range. This is also true of submarines, some ASW helciopters, and some fixed wing aircraft using selected sonobuoys. Some of these systems operate at fixed frequency, and some are tunable over the 9 to 12 kHz band. Other existing systems operate at 10 ± 0.2 kHz. The Burnett Electronics sonar model #538 is a commercially available shipboard unit with a receiving channel in the 8 to 12 kHz band which uses a scanning type hydrophone. It is designed for permanent mounting in a ship's hull, however, it is not widely used. The modulation scheme most commonly used is simple pulse amplitude modulation.

Most of these systems are down-looking and potentially applicable only in the open ocean. The ASW helicopters use side-looking hydrophones and would be more useful in relatively shallow water.

The receivers in these sonar systems all meet the baseline performance characteristics that were the basis for the 64 dB transmitter output requirement derived earlier. As indicated here, a transmitter operating frequency of 10 ± 0.2 kHz with pulsed AM modulation would make the location aid, or attached transponder, compatible with the largest number of potential open ocean search platforms.

A review of commercially available equipment indicates that most receivers designed specifically for search and location problems of the sort considered here are portable or handheld units. These are suitable for use in harbored or reasonably calm coastal waters when deployed from small surface craft. Some relatively high frequency units (30 to 40 kHz) are used by divers to a depth of approximately 200 feet. Certain Government and commercial activities require these units for either day-to-day operations or on an emergency, standby basis. Examples of portable receivers in the 9 to 12 kHz band are the IFCOM PR 2000, the DuKane Corporation N30A15, and the Burnett Electronics #594. These units all satisfy the baseline receiver performance characteristics and are considered applicable for shallow water, near shore location operations.

An initial guideline for this study was that the underwater location aid remain "quiet," for security reasons, until the search craft arrived. This suggests use of a transponder that would not emit until activated by a signal from a search craft. A limited literature review of commercially available devices revealed significant problems for transponders in these applications. Units that meet the 20,000-foot depth requirement are physically too large to be practical attachables in this case. It appears that a more feasible approach for an interim system would be to use a simple transmitting device with a time delayed turnon. The plan would be to program the device to turn on automatically a given time after entering the water. The length of the delay would be based on the typical time for arrival in the search area based on

the particular transport operation and the planned search operation at hand. Acoustic transmitters of reasonable physical size which have been qualified for severe shock and high pressure environment are currently available. A time delayed transmitter would provide security up to the expected time of arrival of the search force, and would require the least amount of development time and cost.

The commercial airline industry is one of the largest users of underwater location aids. According to a Federal Aviation Administration (FAA) directive (FAR 25 and FAR 121), one must be installed on every flight data recorder and every flight deck voice recorder. The FAA developed a severe environment specification (AC No. 21-10A) for these devices. At least two commercial designs have been qualified to this specification and meet the baseline environmental requirments established here. They are the DuKane Corporation model N15F210B and the Burnett Electronics model 590 shown in figures 6 and 7, respectively.

The US Naval Mine Engineering Facility, in support of fleet operations, uses a large number of DuKane N15M210 location aids that meet the baseline environmental requirements. These units are designed to meet NAVSEA specifications for the MK 87 Mod 0 sound source and are currently available through the General Services Administration (GSA) under federal stock number NSN 5845-01-015-2870 (figure 8). They are similar to those used by the National Aeronautics and Space Administration (NASA) in the early 1960s to recover test rockets and scientific payloads launched from the Wallops Flight Test Station (figure 9).

Both the units used by the airline industry and Naval Mine Engineering are activated upon water entry, but neither meet the baseline

acoustic performance requirements established in Section 3. They operate in the 30 to 40 kHz band and would be limited to a range of 5,000 to 10,000 feet.

Another series of high impact location aids was developed by NASA for the Apollo program, and they were also used on some deep space probes (figure 10). This design was later upgraded for use in the Space Shuttle program (Appendix). The devices activate upon water entry and use pulsed AM modulation. In addition, they exceed the baseline acoustic performance requirements that have been established. They operate at 10 kHz with a range of from 26,000 feet to more than 30,000 feet. These devices are available from DuKane Corporation under model number N15A224 (figure 9). The only deficiencies for the interim system application lies in meeting the delayed turnon and depth requirements. The existing design would require modifications to extend the "maximum crush pressure" of the unit from 5,000 psi (11,500 feet) to approximately 10,000 psi (23,000 feet) to exceed the baseline depth requirement.

4.1.3 Hardware Recommendations

To summarize, the existing DuKane Corporation N15A234 transmitter could meet the baseline Air Force requirements and would be compatible with the largest number of existing search and locate platforms and receivers with the least design modifications among all devices surveyed. The required modifications include addition of the time delayed turnon feature and upgrading the crush pressure capability.

A preferred configuration might be to attach one of the larger, longer range 10 kHz units to the transport aircraft and attach the smaller, shorter range 30 to 40 kHz units (Naval Mine Engineering/DuKane N15M210) to the objects to be recovered. The long range device would serve as a location aid for

surface vessels, and the limited range devices would assist submersibles in homing in for recovery. The higher frequency units are a factor of approximately 4 less expensive than the 10 kHz units. They meet the severe environmental and depth requirements, and the delayed timing feature can be applied by replacing the end cap with a timing device (figure 12).

4.2 Recovery

Currently available recovery systems are limited to approximately 12,000 feet for recovering objects of much size; however, the Navy's "Sea Cliff" deep submersible is currently being modified for operation down to 20,000 feet. There are more than 300 submersible vehicles, covering a wide range of capabilities, currently operational worldwide (reference 7). Most are designed for specific jobs or functions with limited flexibility, but some are sufficiently adaptable to be useful here.

There are four principal types of submersible vehicles suitable for recovery and salvage operations--manned free swimming, manned tethered, unmanned tethered, and lockout type diving bells. Curve III (10,000 feet) operated by the Naval Ocean Systems Center (reference 8), is a highly mobile submersible of the unmanned tethered, remotely operated class. SCARAB (6,000 feet) operated by Ocean Search, Inc., and Deep Drone (4,000 feet) operated by the Naval Supervisor of Salvage, are other examples in this class (figures 13 and 14). These systems are designed to be transported by most large aircraft, such as the C-5A, C-141, or Boeing 747, and designed for quick setup on ships of opportunity. A complete system includes the vehicle, an umbilical cable, a power source, and supporting instrumentation.

More efficient systems for medium depth operations are manned tethered vehicles. The WASP (2,000 feet) and the JIM SUITS (1,500 feet), both operated by Oceaneering International et al., are transportable and operate from ships of opportunity.

Lockout vehicles and work bells are primarily designed for long underwater work periods of greater than 100 hours and depths up to 2,000 feet. They must be supported by ships with sophisticated equipment, including decompressing chambers.

Recovery from shallow water (a few hundred feet) can be left to professional divers requiring a minimum of support equipment. Ocean Search, Oceaneering International, and Subsea International are examples of companies that provide this service worldwide. Recovery of explosive devices can be performed by divers in the Navy Explosive Ordinance Disposal Group, with headquarters for Atlantic and Mediterranean operations located at Fort Story, VA. This group is highly mobile and fast acting, and they will normally give assistance to other agencies on a cost reimbursible basis.

The 80th Congress delegated to the US Navy the responsibility for providing salvage services to other Government agencies and civilian organizations on a cost reimbursible basis (Public Law 513).

Request for this service should be directed to Department of the Navy, Chief of Naval Operations (CNO), Washington, DC 20350. The CNO initiates action through OPNAV for the determination of service scope, equipment required, etc., then negotiates a mutual agreement. The Navy has resources available and maintains contracts for highly specialized services in the salvage field. This naval function is detailed in OPNAV Instruction No. 4740.2E and 4740.3A.

The function includes objects with "security interest." Negotiating an agreement with the Navy is highly recommended for the following reasons:

- the Navy owns or controls most deep submersible vehicles;
- the naval vessels required are capable of fast response;
- the Navy owns or contracts for vessels and equipment used in deep sea recovery; and
- the CNO maintains a 24-hour contact duty officer to initiate emergency search and recovery procedures.

5.0 RECOMMENDATIONS FOR AN UNDERWATER LOCATION SYSTEM FOR THE FUTURE

5.1 The Problem

The system outlined in this study, referred to as "interim" is considered the best available approach in cost and time in order to get a location system into the ACES program. However, system performance compromises were necessary to fully utilize existing hardware. Some of the disadvantages of this proposed system are in the areas of security of transmission, receiver, portability, and efficiency of search in waters shallower than 10,000 feet deep.

5.1.1 Security

In order to maintain some control in security, the recommendation to delay the location aid turnon after water entry is a valid one. However, the availability of a search vessel is not known in advance. If the delay time is set too long, a search craft diverted to the search area would have to wait for the timer to activate the location aid transmitter before a search could commence. On the other hand, if availability of a search craft extends beyond the preset delay time, then security could be breached and/or the battery power could be depleted before the object is located.

5.1.2 Receiver Portability

The interim system does not employ a suitable receiver that can be transported and used from a ship of opportunity. The commercially available underwater receivers are primarily handheld. The directional receiving antenna (hydrophone) must be held over the side of a search craft by hand and then rotated or pointed to obtain direction. This works quite well from small craft in calm waters, but is unsatisfactory in the open ocean or for extended search periods. This lack of performance leaves little alternative to the use of the Navy's operational forces. However, these craft are normally heavily committed to their assigned tasks and may not be available when required to conduct a search during an emergency.

5.1.3 Bottom Coverage

The iterim system was designed to utilize the maximum number of available search craft. Most of the compatible receiving systems are designed into the ship's hull and "look" from the surface to the ocean floor through a fixed narrow beam having a total angular width of 10° to 30°. This means that the bottom area covered per unit time (footprint or instantaneous field-of-view) gets proportionally smaller as the water depth decreases. This is satifactory in water greater than about 10,000 feet deep. However, in areas along the Continental Shelf, or other relatively shallow water, the search time is extended because more passes over a given area are required. This becomes important when a search area is large or its boundaries are not well defined.

5.2 A Solution

In order to solve these problems, a systematic development program to address each element of a search and location system is required. The program

must be aimed at end-to-end system performance. The system elements should include the attachable transponder, a transceiver and hydrophone system, portable platform, and any interface requirements for current standard shipboard systems. This system should be usable on ships of opportunity, including the naval operational force vessels, and should be transportable worldwide during any emergency.

5.2.1 Development Approach

During the development phase, major elements of the proposed system should be assigned priority according to the overall system improvement offered by each development. This could be accomplished in the following suggested order:

- Develop a preliminary design for the entire search system.
- Design and develop a cryptographic key code system for emission control of the attachable transponder.
- Develop a transceiver to operate with a coded attachable transponder. This transceiver should be compatible with the proposed time programmed interim attachable acoustic transmitters and adaptable for use on current vehicles like the Navy's Deep Tow, STSS, Teleprobe, and some deep submersible vehicles.
- Develop an underwater towed platform for the transceiver and hydrophone assembly.
- Develop a coded attachable underwater transponder.
- Exercise the option to develop compatible interface equipment for existing shipboard systems as considered feasible.

5.2.2 A System Concept

A basic systems block diagram is given in figures 15 and 16. This approach is centered around a microprocessor based attachable transponder. This device must receive a special cryptographic key code command in order to be activated. Once activated the device can function in a number of operating modes. A rhythmic low frequency pulsed transmitter for acquisition and homing, a transponder for ranging, and resettable to the key code off condition, are examples of operational modes available. The search transceiver can be used to interrogate the attachable device, issue commands, process return signals, and display range and directional information in real time. The proposed transceiver is also compatible with the timed transmitters in both the 10 kHz and 38 kHz bands. One unique feature of the proposed system is the utilization of "spread spectrum" emission. The advantage of this type of emission is the ability to transmit more data per unit time with greater security and less bit error rate over moderate ranges.

5.2.2.1 Search Transceiver

The proposed transceiver would be designed to function as a tunable single frequency receiver with pulse detection in both the 38 kHz and the 10 kHz frequency bands. Directional characteristics are determined, in part, by the receiving hydrophone and by electronic manipulation of the beam patterns. The transceiver can be programmed with specific key code commands to activate the attachable transponder under search. It issues the interrogration key code complete with parity and sync on a spread spectrum format, sending 16-bit words in parallel. When the attachable transponder is activated by the

special key code, the transceiver issues selected operating mode commands, then receives and displays data in real time.

The output from the transceiver can be programmed to be compatible with a specific coding design. For security enhancement the proposed transmission is based on a spread spectrum format using 16 discrete frequency data channels within a bandwidth of 9 to 12 kHz. Words containing 16 binary bits are transmitted simultaneously, and a given number of words constitutes a frame which defines the particular code in use. Pulse modulation is applied in a return to zero format. Channels carrying a binary one are transmitting and channels carrying binary zero are not. A data transmission rate of 160 bits/sec is reasonable. This rate transmitted over a 30° bandwidth from a hydrophone towed at 15 knots would, for example, deliver more than 10 kilobits of data to a transponder within the footprint at 1000 meters depth. At 6100 meters (maximum depth) more than 65K bits would be delivered on a single pass over the transponder.

The complexity of a selected cryptographic code to enable the transponder will determine the number of bits and/or transmission time required to send the complete key message.

5.2.2.2 Display and Control

The receiver could be controlled from a shipboard console which includes the display of processed data. Transmission coding and format can be keyed in and stored in memory for the specific unit under search and programmed for automatic sequencing. A display using a matrix of light emitting diodes or a liquid crystal screen is considered adequate to display range and directional data from the transponder. Some system housekeeping measurements could also

be included. Modular construction is proposed with preamplification, high current demand circuitry, and transducer beam control circuitry to be mounted in the hydrophone assembly.

5.2.2.3 Transponder

The attachable transponder is required to be in a standby condition following water entry. A very low current drain receiver will remain in an "on" condition to accept coded signals from the search craft. The input of a cryptographic message will be received through a 16-channel acoustic link and processed. The cypher text is combined with a unique decryption key code filed within the transponder to form a complete key message. When a valid message is formed, the transponder is activated, and then responds to the specific programmed instructions.

Scattering and reflections of incoming signals, particularly in the area around a wreckage or in shallow water, causes signals to arrive at the transponder from different directions (multipath) delayed in time. This causes "intersymbol" interference. With a relatively low bit rate requirement, this problem can be addressed by using long duration (80 ms) pulses. The received signal is passed through 16 matched filters to optimize detection and then integrated. A period of 10 milliseconds is inserted between each word to reduce energy spillover from the preceding bit.

Operating modes.- The transponder, when activated by the key code, emits single frequency periodic pulses. Continuous pulsing (pinging), a single pulse response for each interrogation (for ranging), changing output power, shifting frequency, or reset back to key code are possible alternative operating modes.

State-of-the-art circuitry must be employed to keep the size, weight, and standby current drain to a minimum. A size of approximately 2.5 inches by 10 inches and cylindrical in shape appears feasible. A projected weight of under 4 pounds, including the battery, is considered attainable. Other characteristics, including environmental, will be based on those contained in the Appendix.

5.2.2.4 Receiver Hydrophone Assembly (Antenna)

The receiver hydrophone must be usable on a ship of opportunity, portable, and suitable for open ocean search over extended periods of time. The approach considered for this system is a hydrophone assembly mounted in a stabilized platform that can be towed by a cable from the stern of a ship. A primary function of the hydrophone, which is analogous to an antenna in the RF case, is to provide directional discrimination in receiving signals from the transponder so that its location can be determined. Two methods for getting the required directionality plus the required coverage will be discussed.

5.2.2.4.1 Fixed Beam

This system is designed around an instrument carrying underwater depressor, developed for the Naval Research Laboratory by the EDO Western Corporation. This depressor (figure 17) has been tested in different sizes and can be towed at speeds up to 40 knots. It is designed to be towed on a short tow cable within 300 feet of the surface at a speed that depends upon the depth of tow.

It is proposed to modify an existing unit, or build a similar one, to include a shaded and baffled line transducer along the leading edge of each

wing with a beam pattern of 25° in the horizontal plane and 60° in the vertical plane. Used principally as forward looking, these transducers are mounted such that the acoustic axis in the vertical plane is tilted downward 5 to 10°. The axis of the horizontal plane will be offset 10° to each side of the center line along the forward heading of the depressor. Received signal amplitudes from each transducer will be electronically processed to determine direction. Additionally, a similar design will be mounted on a sting protruding from the rear of the depressor. This unit will be essentially down looking with a beam angle of 30° in the vertical plane (fore and aft) and approximately 180° in the horizontal plane (side looking). These assemblies will be designed to operate in the 9 to 12 kHz frequency band in transmit and receive and 30 to 40 kHz band in receive only. The concept is illustrated in figure 18.

5.2.2.4.2 Electronically Scanned Beam

A hydrophone system that scans the acoustic beam plus and minus 90° is considered a distinct advantage over a fixed beam system. This optional system uses 48 discrete resonant crystal assemblies mounted in a semicircle, and forms a part of the forward periphery of the depressor (figure 19). The elements are arranged to produce a beam of approximately 20o in the vertical plane and 60° in the horizontal plane, and can be electronically switched to scan the beam ±90° about the forward heading. The scan rate is variable, and scanning is in increments of 4°. This option would also have a sting protruding from the back of the unit with a 30° by 180° beamwidth crystal assembly. This antenna is used to transmit at 10 kHz for transponder interrogation and receive at 10 kHz or in the 30 to 40 kHz band. See figure 20 for a sketch of this concept.

5.2.2.5 Interrogation Coding

The coding technique chosen to enable the attachable transponders should meet two criteria:

(a) that the code is strong enough to allow an acceptable degree of security, and

(b) that the code not be so complex that it would be impractical to transmit over an acoustic link.

Obviously the decryption code could by chance be intercepted by an intruder while a search was being conducted. The code would essentially be broken for the unit under search. However, this could have little impact because the search forces would be in the recovery area, and remain until the recovery was completed.

The important thing is to have a code strong enough to be impractical to decrypt without an appropriate key. Then each attachable transponder could be programmed for a unique key code. Choice of a coding system must be within the capability of the proposed system to transmit the message within a reasonable time frame.

Crypotgraphy is a very specialized science and it is not within the scope of this report to attempt to devise a coding system. However, a coding scheme proposed by Adleman, Revist et al. (reference 9) was used to evaluate the feasibility of the double key code approach. This system is based on the use of three selected prime numbers for the encryption and decryption procedures. As an example let p, q and e represent selected prime numbers, where

c = a cypher text message transmitted to the transponder

d = part of the decryption code; computed from the selected prime number "e," such that (d) (e) has a value of 1 when dividing by ϕ

$\phi = (P - 1) \quad (q - 1)$

N = the product of P and q

M = a number representing a plain text message, for example,

2 = enable transmitter

3 = go to transponder mode

4 = go to standby

5 = return to key code off, etc.

The encryption procedure is

$$c = m^e \bmod N$$

Choosing a set of prime numbers where $P = 5$, $q = 11$ and $e = 7$ the key codes can now be computed: $N = 55$, $\phi = 40$, $d = 23$ <d,N> is the decryption code and is filed in the transponder memory. Therefore, to enable the transponder, let $M = 2$ (from the table above). The cypher text transmitted to the transponder is:

$$\begin{aligned} c &= m^e \bmod N \\ &= 2^7 \bmod 55 \\ &= 18 \end{aligned}$$

The decryption procedure is

$$\begin{aligned} m &= c^d \bmod N \\ &= 18^{23} \bmod 55 \\ &= 2 \end{aligned}$$

which represents the plain text message assigned to enable the transponder.

There are several key code cryptosystems which appear suitable. The volume of data to be transmitted is low. All conceivable commands or instructions required could be handled in one-byte words. However, the key code that must be transmitted to have these data accepted could become many characters long if a large quantity of transponders were produced with each having a different key code. The problem of sending very long data streams through the water without error would become demanding. The first impact would be a forced reduction of maximum search speed to allow enough transmission time over the transponder. Should a problem exceed practical limits there are options and/or procedures available to manage it. One option would be a weaker coding scheme; for example, establishing small blocks or groups of key code number sets and changing them periodically, or changing them only when breached. Adding error correction to the transmitted data or changing the transmission format are other options to consider.

6.0 SUMMARY

A study to provide the USAF Weapons Laboratory with information related to the location and recovery of military hardware lost in the ocean has been presented. Acoustic devices attached to an object prior to being transported is suggested as an aid for locating the object underwater. Minimum requirements and some environmental constraints have been defined. Methods and procedures for search and recovery are also discussed.

Commerically available hardware is identified that with modification will meet the minimum requirements for an "interim" location system. This system is largely dependent on availability of the naval operational forces for support in an ocean recovery operation. Congressional authority and Chief of Naval Operations (OPNAV) instructions for this responsibility have been referenced here. Suggestions for implementing an agreement for naval assistance is included as well.

Security of jettisoned cargo has been considered throughout this study and has been addressed for the "interim" system. The modification to standard commercial components required for this "interim" system include timed turnon for security and lifetime considerations plus an increase in operating depth capability.

Finally, a development program for an advanced search system is suggested that will further enhance security and increase the effectiveness of the location operation. A coded underwater transponder activation scheme is suggested. The transponder may be activated by a near surface transmitter, then located using multiple element steerable beam hydrophones. This configuration will optimize bottom coverage. This relatively portable receiving system would minimize or eliminate the dependence upon a certain class of our operational forces, and extend the search capability to any available vessel.

REFERENCES

1. Signals Underwater Sound (SUS), NAVAIR Tech. Manual Number 11-1-107 (First Rev.), pp 3.2-3.10, September 1971.

2. Tracking and Data Relay System (TDRSS) Users Guide (Rev. 4), STDN No. 101.2, Goddard Space Flight Center, Greenbelt, MD 20771, January 1980.

3. Castle, C. B. and Alfaro, E, - Bou E., Light Airplane Crash Tests at Three Flight Path Angles, NASA TN 1210, National Aeronautics and Space Administration, Langley Research Center, Hampton, VA 23665, June 1978.

4. Bennett, C. B., Acoustic Beacon Survival in Satellite Abort, NDRC TR-68-92, US Naval Radiological Defense Laboratory, San Francisco, CA 94135, August 1968.

5. Urick, R. J., Principals of Underwater Sound for Engineers, McGraw Hill Publishing Co., New York, pp. 21-23, 1967.

6. Fisher, R. B. and Rich, P. M., Locator Beacon Detection Ranges for Fuselage Encapsulated Recorders FAA Report No. NA-68-7, Dept. of Transportation, FAA National Aviation Facilities Experiment Center, Atlantic City, NJ 08405, February 1968.

7. Manual of Manned Submersibles US Naval Oceanographic Command NSTC Station, Bay St. Louis, MS 39529, September 1982.

8. Catalog of Deep Submergence Systems (Unmanned), Rpt. No. 59DSV-00-CAT-010, Dept. of the Navy, Sea Systems Command, Code 05L3, Washington, DC 20362, April 1981.

9. Adlemen, L. M. and Rivest, R. L., The Use of Public Key Cryptography in Communications System Design, IEEE Communications Society Magazine, Vol. 16, No. 6, pp 20-23, November 1978.

APPENDIX

DEVELOPMENT SPECIFICATIONS FOR

UNDERWATER LOCATION AID

(DuKane Model No. N15A234)

1.0 OPERATIONAL CHARACTERISTICS

1.1 Frequency

The frequency shall be 10 kHz ± 200 Hz.

1.2 Emission

Emission shall be pulsed continuous wave.

1.2.1 Pulse Duration

Pulse duration shall be 12.5 ms ± 2.5 ms.

1.2.2 Pulse Repetition Rate

The pulse repetition rate shall be 1.4 sec ± 0.6 sec.

1.2.3 Acoustic Output

Shall not be less than 170 dB//μPa/cm^2 rms average, measured at a distance of 1 meter on a line perpendicular to the acoustic axis of the device. All measurements shall be in accordance with standard ANSI-SI.20 (1972). The output shall be determined by recording and averaging the output at intervals of no more than 10° equally spaced taken about the polar pattern when rotated 360°.

1.2.4 Polar Radiation

The acoustic output measured 360° about the major axis on a plane perpendicular to the emitting face shall be such that the acoustic output is down not more than 2 dB at any point from 170 dB//μPa/cm^2.

1.2.5 Switching

Switching shall be water activated and reusable. Must develop full acoustic output power when submerged in either fresh tap or saltwater.

1.2.6 Power Source

The ULA shall be powered by a self-contained mercury battery made from eight type 1450 cells having a voltage of 10.5 V ± 0.5 V. Manufacturer of this battery shall include the cell manufactured date clearly marked on the label.

1.2.6.1 Standby Leakage Current

In switch off condition the current drain from the power source shall not exceed 3 μa.

1.2.7 Case or Housing Material

Case material shall be titanium type 6AL4V with a $\sqrt{63}$ finish or better.

1.2.8 Operating Life

The operating lifetime shall be 240 hours minimum. The end of life shall be determined when the acoustic output drops below 167 dB/μPa/cm^2/m.

1.2.9 Weight

The total weight shall be 40 ounces or less.

1.2.10 Size

The overall size of the unit, excluding mounting hardware, shall be 2.340 ± 0.003 inches in diameter and 7 ± 0.01 inches long.

1.2.11 Markings

All markings on outer case shall be made by either engraving or etching process ink, paint, or other coatings shall be avoided. Markings on body of unit shall be limited to part or model number, serial number, manufacturer's name and address, and NASA contract number. End caps may be marked with special instruction.

1.2.12 Mounting Brackets

The manufacturer shall provide DuKane part number 810-784 and 810-785 installed as an integral part of each ULA to permit mounting ULA to parachute shroud lines. All tests shall be conducted without mounting brackets installed unless otherwise noted.

2.0 DOCUMENTATION

2.1 Drawings

The contractor shall provide mechanical interface and top assembly drawings in reproducible format, parts and material lists.

2.2 Test Reports

All test data developed during the testing of production devices shall be delivered in the form of certified testing laboratory reports and/or official company test reports. Company test reports shall be submitted with the backup raw data collected during testing. Raw data shall be certified by a representative of the contracting officer.

2.2.1 Certification

Following the successful completion of the certification tests outlined in Section 5.0, the manufacturer shall initiate a certificate of qualification (COQ) for the highest mission level achieved.

2.3 Inspection

Certification of qualification requires 100 percent inspection. During testing of production models all tests shall be observed by a representative of the contracting officer. Notification of test schedule shall be made at least 2 weeks in advance. Further, all tests should be coordinated to be accomplished in an orderly manner to reduce the in-house time for Government inspectors.

3.0 ENVIRONMENTAL TEST LEVELS

3.1 Thermal Cycling

3.1.1 Temperature

Storage and transport (nonoperational) minus -40° F to 165° F.

> Note: The temperature requirement given in paragraph 3.1.1 for storage and transport is a goal for endurance testing only. The results shall not dictate completely component design but could preclude the necessity for more stringent shipping and handling procedures.

3.1.2 Temperature

(Operating) 50^{o} F to 150^{o} F.

3.1.3 Thermal Shock

(Water immersion) Plus 28^{o} F in air to 175^{o} F in air, into ambient water (50^{o} to 70^{o}). (Operational in water only.)

3.1.4 Water Immersion

Shall withstand being submerged under maximum operating pressure (75 psi) for a period of at least 10 hours, and also the maximum rated pressure, 5000 psi for a period not less than 10 hours.

3.2 Saltwater Tolerance

The case shall show no significant corrosion or other detrimental effects after being submerged in saltwater (50^{o} to 70^{o} F) for a minimum period of 7 days. A substitute seawater solution in accordance with American Standard ASTM D1141-52 shall be used.

NOTE: The following alternate solution may be used to meet the saltwater tolerance test.

NaCl (c.p.)	23 grams
$Na_2SO_4.10H_2O$	8 grams
Stock Solution	20 ML

Add sufficient distilled water to make 1 liter.

Stock solution consists of the following:

KCl (c.p.)	10 grams
KBr (c.p.)	45 grams
$MgCl_2.6H_2O$ (c.p.)	550 grams
$CaCl_2.6H_2O$ (c.p.)	110 grams

Add sufficient distilled water to make 1 liter.

3.3 Pressure

3.3.1 Vacuum

(Nonoperating) The device shall exhibit no leakage, outgassing or other detrimental effect when subjected to a vacuum equivalent to an altitude of 270,000 feet.

3.3.2 Hydrostatic

(Operating) The ULA shall withstand a hydrostatic pressure of a minimum of 5,000 psi without distortion, cracking, or other damage to the water-tight integrity of the device.

3.4 Vibration

3.4.1 Acceptance

Radial Axis	Long. and Tang. Axis
20 Hz @ 0.013 g^2/Hz	20 Hz @ 0.016 g^2/Hz
20 - 500 Hz @ +3 dB/oct	20 - 150 Hz @ + 3 dB/oct
500 - 700 Hz @ 0.32 g^2/Hz	150 - 1000 Hz @ 0.12 g^2/Hz
700 - 2000 Hz @ -9 dB/oct	1000 - 2000 Hz @ 9 dB/oct
2000 Hz @ 0.014 g^2/Hz	2000 Hz @ 0.015 g^2/Hz
Composite = 15.7 g_{rms}	Composite = 12.5 g_{rms}

3.4.2 Lifeoff Random

Random Axis

20 Hz @ 0.0054 g^2/Hz
20 - 150 Hz @ +3 dB/oct
150 - 320 Hz @ 0.040 g^2/Hz
320 - 400 Hz @ +6 dB/oct
400 - 800 Hz @ 0.065 g^2/Hz
800 - 2000 Hz @ -9 dB/oct
2000 Hz @ 0.0042 g^2/Hz

Composite = 7.9 g_{rms}

Long. and Tang. Axis

20 Hz @ 0.010 g^2/Hz
20 - 100 Hz @ +3 dB/oct
100 - 150 Hz @ 0.050 g^2/Hz
150 - 190 Hz @ -6 dB/oct
190 - 1000 Hz @ 0.030 g^2/Hz
1000 - 2000 Hz @ -6 dB/oct
2000 Hz @ 0.0075 g^2/Hz

Composite = 6.8 g_{rms}

3.4.3 Boost Random

Radial Axis

20 Hz @ 0.015 g^2/Hz
20 - 600 Hz @ +3 dB/oct
600 - 1000 Hz @ 0.44 g^2/Hz
1000 - 2000 Hz @ -9 dB/oct
2000 Hz @ 0.055 g^2/Hz

Composite = 21.8 g_{rms}

Long. and Tang. Axis

20 Hz @ 0.028 g^2/Hz
20 - 80 Hz @ +3 dB/oct
80 - 360 Hz @ 0.11 g^2/Hz
720 - 1300 Hz @ 0.22 g^2/Hz
1300 - 2000 Hz @ -9 dB/oct
2000 Hz @ 0.060 g^2/Hz

Composite = 17.5 g_{rms}

3.4.4 Reentry Random

Radial Axis

20 Hz @ 0.052 g^2/Hz
20 - 500 Hz @ +3 dB/oct
500 - 700 Hz @ 1.30 g^2/Hz
700 - 2000 Hz @ -9 dB/oct
2000 Hz @ 0.056 g^2/Hz

Composite = 31.4 g_{rms}

Long. and Tang. Axis

20 Hz @ 0.064 g^2/Hz
20 - 150 Hz @ +3 dB/oct
150 - 1000 Hz @ 0.48 g^2/Hz
1000 - 2000 Hz @ -9 dB/oct
2000 Hz @ 0.060 g^2/Hz

Composite = 25.0 g_{rms}

3.4.5 Vehicle Dynamics

Transit 3 octive/min

Longitudinal Axis

6 - 40 Hz @ 1.0 g's peak

Lateral Axis

5 - 10 Hz @ 0.6 g's peak
10 - 40 Hz @ 1.7 g's peak

3.5 Shock Test Criteria

3.5.1 Forward Skirt/Frustum Separation

	50 Hz	@ 57 g's peak
50 -	100 Hz	@ +12 dB/oct
	100 Hz	@ 188 g's peak
100 -	4000 Hz	@ +6 dB/oct
4000 -	10000 Hz	@ 7500 g's peak

3.5.2 Acceleration

Parachute Malfunction

2000 g's half sine pulse

2 msec duration each of the three axis

4.0 QUALIFICATION CERTIFICATION TESTS

Production units shall be subjected to tests to simulate a Shuttle launch, flight, reentry, water landing, and recovery. Each test shall be performed in accordance with an appropriate test procedure prepared by the Government and mutually agreed upon between the Government and contractor for each specific test series. Prior to multimission certification each ULA must first pass the acceptance tests outlined in this section. Mission certification tests shall be conducted for a single mission on six units; for seven missions on four units, and twenty missions on two units.

4.1 Operational Baseline

This test is to determine the operational characteristics of the ULA and is repeated throughout the test program to determine effects of environmental stress. Measurements are taken in free field water or suitable anechoic facility at a distance normalized to 1 meter.

- Frequency (Section 2.1)
- Emission (Section 2.2)
- Pulse Duration (Section 2.2.1)
- Pulse Repetition Rate (Section 2.2.2)
- Acoustic Output Sound Pressure at 1 meter (dB//μPa/cm^2) (Section 2.2.3)
- Polar Radiation Plot (Section 2.2.4)
- Switching (Section 2.2.5)
- Battery Voltage (Section 2.2.6)
- Switch Off Standby Current (Section (2.2.6.1)

All data shall be recorded and identified to the preceding test sequence.

4.2 Flight Acceptance Test

4.2.1 Saltwater Tolerance

This test is performed one time only. (NOTE): This is a passive test and does not require continuous monitoring.) The case shall be submerged in a standard seawater solution (ASTM D1141-52 or equivalent) at ambient pressure for a period of 7 days without corrosion, pitting, or other detrimental effects. Test tank shall be nonmetallic and water shall be maintained between 50° to 70° F throughout the test. Visually inspect outer surface for pits or corrosion. Inspect interior for leakage.

4.2.2 Thermal

The device shall operate normally when subjected to a temperature range of 50° F to 150° F (five cycles). Lower temperature to 50° F let stabilize plus 1 hour; raise to 150° F let stabilize plus 1 hour. Return to ambient then function check. This constitutes one thermal cycle.

4.2.2.1 Functional Check

A functional check is conducted by shorting the water switch to activate the unit in air then monitor output on a DuKane type 42A12 test set.

4.2.3 Vibration Random

Radial Axis	Long and Tang. Axis
20 Hz @ $0.013\ g^2/Hz$	20 Hz @ $0.016\ g^2/Hz$
20 - 500 Hz @ +3 dB/oct	20 - 150 Hz @ +3 dB/oct
500 - 700 Hz @ $0.32\ g^2/Hz$	150 - 1000 Hz @ $0.12\ g^2/Hz$
700 - 2000 Hz @ -9 dB/oct	1000 - 2000 Hz @ -9 dB/oct
2000 Hz @ $0.014\ g^2/Hz$	2000 Hz @ $0.015\ g^2/Hz$
Composite = $15.7\ g_{rms}$	Composite = $12.5\ g_{rms}$

Vibrate each unit 60 sec in each of three orthogonal axis. Functional check (4.2.2.1) after each axis test.

4.2.4 Pressure

4.2.4.1 Altitude

The device shall exhibit no leakage, outgassing, or other detrimental effects when subjected to a simulated altitude of 270,000 feet. Start test at ambient atmospheric pressure; lower pressure to 5 microns; hold for 3 minutes; raise pressure to one atmosphere over a period of 5 plus or minus 1 minute; function check (4.2.2.1) at ambient pressure.

4.2.4.2 Hydrostatic

The outer housing shall withstand a hydrostatic pressure of 5,000 psi without distortion, cracking, or other damage to the water-tight integrity.

Install ULA device into a small container filled with ambient tap water. Install filled container into a hydraulic pressure chamber. Raise

pressure in 1,000 psi increments to 5,000 psi. Observe and record frequency, pulse length, and pulse rate of each incremental pressure.

4.2.5 Operation Baseline

Repeat test outlined in Section 4.1.

4.3 Mission Certification Qualification Criteria

4.3.1 Thermal Cycling

Thermal cycling shall be conducted in both operational and nonoperational mode as outlined in 4.3.1.1 and 4.3.1.2 below. Conduct tests for each mode by cycling between both extremes; five cycles for one mission; plus ten cycles through seven missions; plus twenty cycles through twenty missions, starting at ambient decrease to lowest mode temperature. Maintain until unit stabilizes plus 1 hour, raise temperature to highest mode level. Maintain until stabilization plus 1 hour, decrease to lowest mode temperature, maintain until stabilization plus 1 hour. This constitutes one thermal cycle.

4.3.1.1 Nonoperational Storage and Transport

Device shall withstand temperatures from minus 40° to 165° F. Functional check at ambient temperature.

4.3.1.2 Launch Pad, Flight, Reentry and Recovery

The device shall operate normally at any temperature between plus 50° F and 150° F. Functional check conducted at each temperature extreme.

4.3.2 Operational Baseline

Conduct test outlined in Section 4.1.

4.3.3 Acceleration

This is a parachute malfunction test. The device must operate within specification after acceleration of 2,000 g for 2 milliseconds in each of three orthogonal planes; one cycle for one through twenty missions.

4.3.4 Operational Baseline

Repeat tests outlined in Section 4.1.

4.3.5 Vibration

4.3.5.1 Vehicle Dynamics

Sine.

Longitudinal Axis	Lateral Axis
6.0 - 40 Hz @ 1.0 g peak	5 - 10 Hz @ 0.6 g's peak
	10 - 40 Hz @ 1.7 g's peak

Transit three octives per minute; transit up one time for one mission; transit back for seven missions; transit up and back for twenty missions.

4.3.5.2 Lifeoff Random

Random Axis	Long. and Tang. Axis
20 Hz @ 0.0054 g^2/Hz	20 Hz @ 0.010 g^2/Hz
20 - 150 Hz @ +3 dB/oct	20 - 100 Hz @ +3 dB/oct
150 - 320 Hz @ 0.040 g^2/Hz	100 - 150 Hz @ 0.050 g^2/Hz
320 - 400 Hz @ +6 dB/oct	150 - 190 Hz @ 6 dB/oct
400 - 800 Hz @ 0.065 g^2/Hz	190 - 1000 Hz @ 0.030 g^2/Hz
800 - 2000 Hz @ -9 dB/oct	1000 - 2000 Hz @ -6 dB/oct
2000 Hz @ 0.0042 g^2/Hz	2000 Hz @ 0.0075 g^2/Hz
Composite = 7.9 g_{rms}	Composite = 6.8 g_{rms}

Vibrate 60 sec on each of three orthogonal axis for one mission; plus an additional 60 seconds per axis for seven missions; plus an additional 130 sec per axis for twenty missions.

4.3.5.3 Boost Random

Radial Axis	Long. and Tang. Axis
20 Hz @ 0.015 g^2/Hz	20 Hz @ 0.028 g^2/Hz
20 - 600 Hz @ +3 dB/oct	20 - 80 Hz @ +3 dB/oct
600 - 1000 Hz @ 0.44 g^2/Hz	80 - 360 Hz @ 0.11 g^2/Hz
1000 - 2000 Hz @ -9 dB/oct	360 - 720 Hz @ +3 dB/oct
2000 Hz @ 0.055 g^2/Hz	720 - 1300 Hz @ 0.22 g^2/Hz
	1300 - 2000 Hz @ -9 dB/oct
	2000 Hz @ 0.060 g^2/Hz
Composite = 21.8 g_{rms}	Composite = 17.5 g_{rms}

Vibrate 120 sec/axis for one mission; plus an additional 240 sec/axis for seven missions; plus 520 sec/axis for twenty missions.

4.3.5.4 Reentry Random

Radial Axis	Long. and Tang. Axis
20 Hz @ 0.052 g^2/Hz	20 Hz @ 0.064 g^2/Hz
20 - 500 Hz @ +3 dB/oct	20 - 150 Hz @ +3 dB/oct
500 - 700 Hz @ 1.30 g^2/Hz	150 - 1000 Hz @ 0.48 g^2/Hz
700 - 2000 Hz @ -9 dB/oct	1000 - 2000 Hz @ -9 dB/oct
2000 Hz @ 0.056 g^2/Hz	2000 Hz @ 0.060 g^2/Hz
Composite = 31.4 g_{rms}	Composite = 25.0 g_{rms}

Vibrate 90 sec per axis for one mission; plus 180 sec per axis for seven missions; plus 390 sec per axis for twenty missions.

4.3.6 Operation Baseline

Repeat test outlined in Section 4.1.

4.3.7 Shock Test Criteria

Because of the special nature of the shock criteria, Government facilities will be provided for this test. Arrangements should be made through the contracting officer at an early date (90 days lead time).

4.3.7.1 Forward/Skirt/Frustum Separation

	50 Hz @ 47 g's peak
50 -	100 Hz @ +12 dB/oct
	100 Hz @ 188 g's peak
100 -	4000 Hz @ +6 dB/oct
4000 -	10000 Hz @ 7500 g's peak

4.3.7.2 The ULA shall be tested on the live ordnance facility located at the Marshall Space Flight Center, Huntsville, Alabama; one live ordnance test for each unit per mission (i.e., one exposure per unit for six units for one mission certification; plus six exposures for four units for seven mission certifications; plus thirteen exposures for two units for twenty mission certifications).

4.3.8 Thermal Shock

The device shall withstand a rapid temperature change from 28° F to 175° F. To test lower temperature 28° F, let stabilize plus 1 hour; then accelerate outer surface of case to 175° F; remove from environment and immediately immerse in water having an ambient temperature of 50° F to 70° F. This test shall be conducted one time for one mission; three times for seven missions; and six times for twenty missions. This test shall also be combined with water immersion (Section 4.3.9).

4.3.9 Water Immersion

Wtihin 120 sec following the first thermal shock cycle (4.3.8), immerse the specimen in ambient water (50° F to 70° F) then pressurize to 75 psi within 90 sec. Maintain pressure for a minimum of 10 hours. Repeat this test on the fourth thermal shock cycle. Repeat again on the tenth and last thermal shock

cycle except for this cycle increase pressure to 5,000 spi within 120 sec and hold for a period not less than 10 hours. During the water immersion test the ULA will be operational and may be monitored by use of an ultrasonic test set. Following the 5,000 psi test raise to ambient pressure, remove specimen and inspect external housing for damage and internally for leakage.

4.3.10 Operational Baseline

Repeat test outlined in Section 4.1.

5.0 SPECIAL INSTRUCTIONS

5.1 Test Sequence

All tests included in Section 5.0 shall be conducted in the order listed. Tests for all missions will be completed in each environmental category before proceeding to the next section.

5.1.2 Test Equipment

Test equipment used for measurement during tests shall be calibrated. Calibration should be traceable to a prime standard. Test equipment shall have an accuracy at least one-third of the accuracy required for the parameter being measured. Equipment nomenclature shall be included in all reports including make, model, range, accuracy, and date of last calibration.

5.1.3 Test Tolerances

Unless otherwise specified, allowable tolerances for all test conditions shall be as follows.

5.1.3.1 Acceleration

Plus 30 percent minus 10 percent.

5.1.3.1.1 Time Base

Plus 10 percent minus 0.

5.1.3.2 Acoustics

Plus or minus 2 dB.

5.1.3.3 Altitude

Plus or minus 10 percent.

5.1.3.4 Frequency

Plus or minus 2 percent.

5.1.3.5 Shock

Pulse plus or minus 15 percent.

5.1.3.5.1 Shock Spectrum

Plus 40 percent minus 20 percent.

5.1.3.6 Temperature

Tolerance--plus or minus 2° F.

5.1.3.7.1 Temperature

Stabilization--when centrally located interior part or component with the largest thermal inertia has stabilized within 2° F of specified temperature.

5.1.3.8 Time

Plus 10 percent minus 0.

5.1.3.9 Vibration

5.1.3.9.1 Acceleration

Random (g rms)--Plus or minus 10 percent.

5.1.3.9.2 Spectral Density

Power (g^2/Hz)--Plus 100 percent minus 30 percent.

5.1.3.9.3 Acceleration

Sine--Plus 20 percent minus 10 percent.

5.1.3.9.3.1 Frequency

Plus or minus 5 percent.

5.1.3.9.4 Test Duration

Plus 10 percent minus 0.

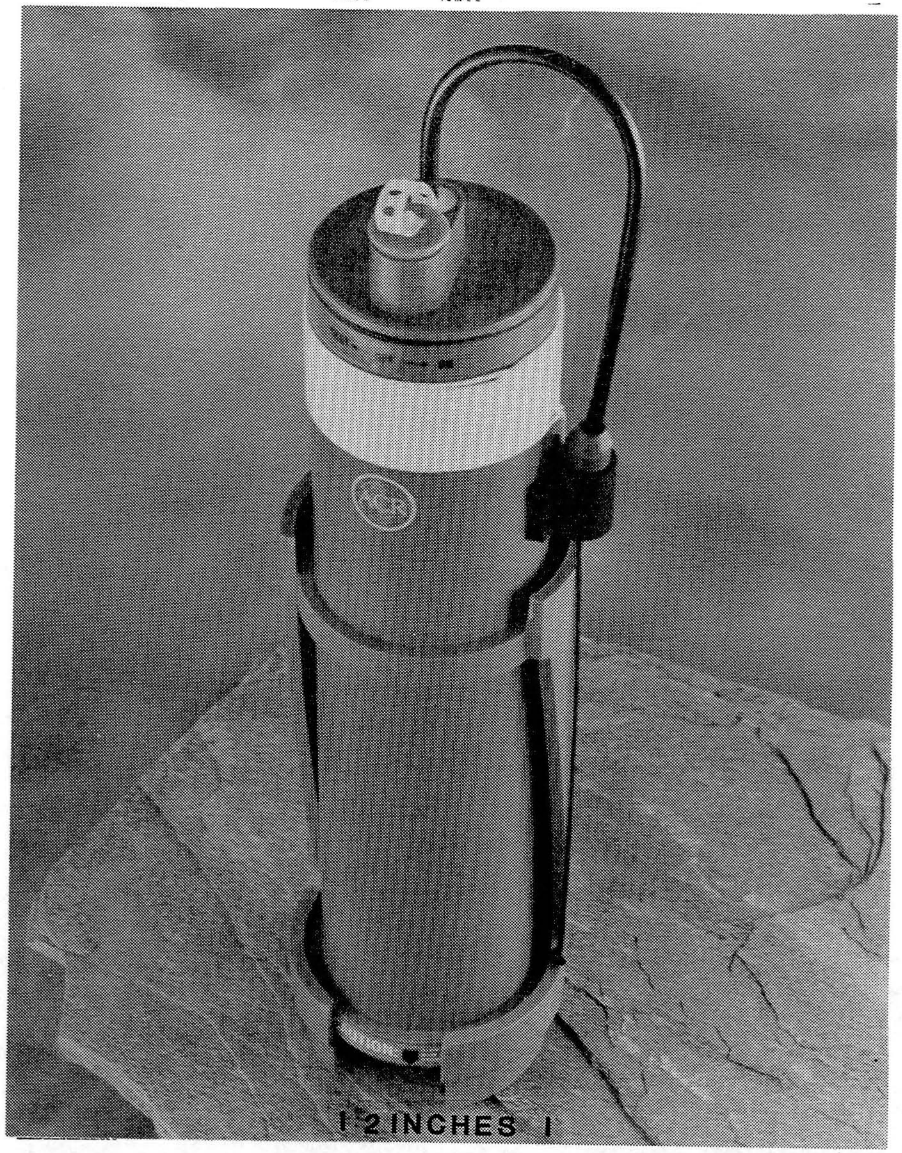


Figure 1.- Emergency Position Indicating Radio Beacon (EPIRB).

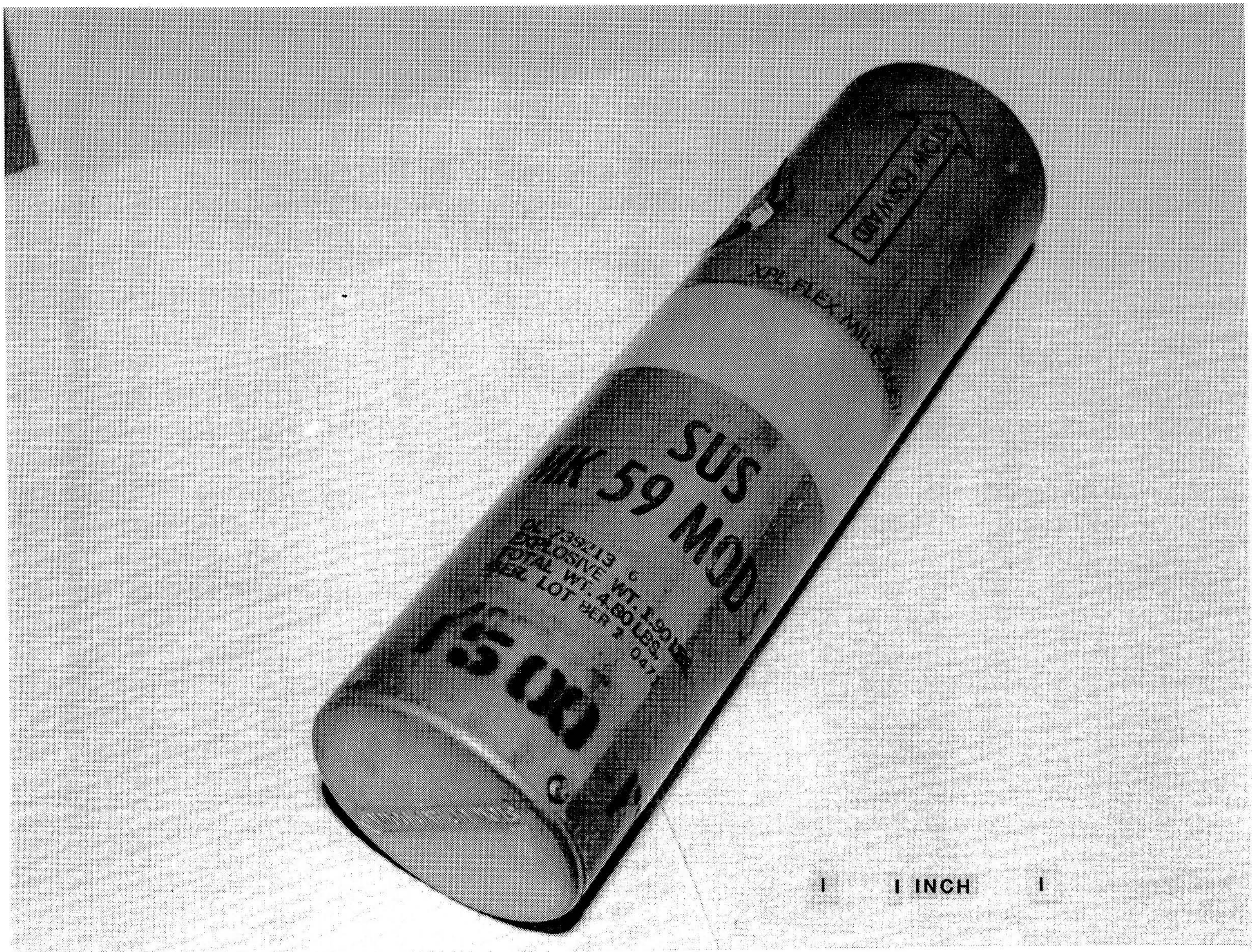


Figure 2.- Navy sound signaling device type MK 59 Mod 5 for use in deep ocean sound channel.

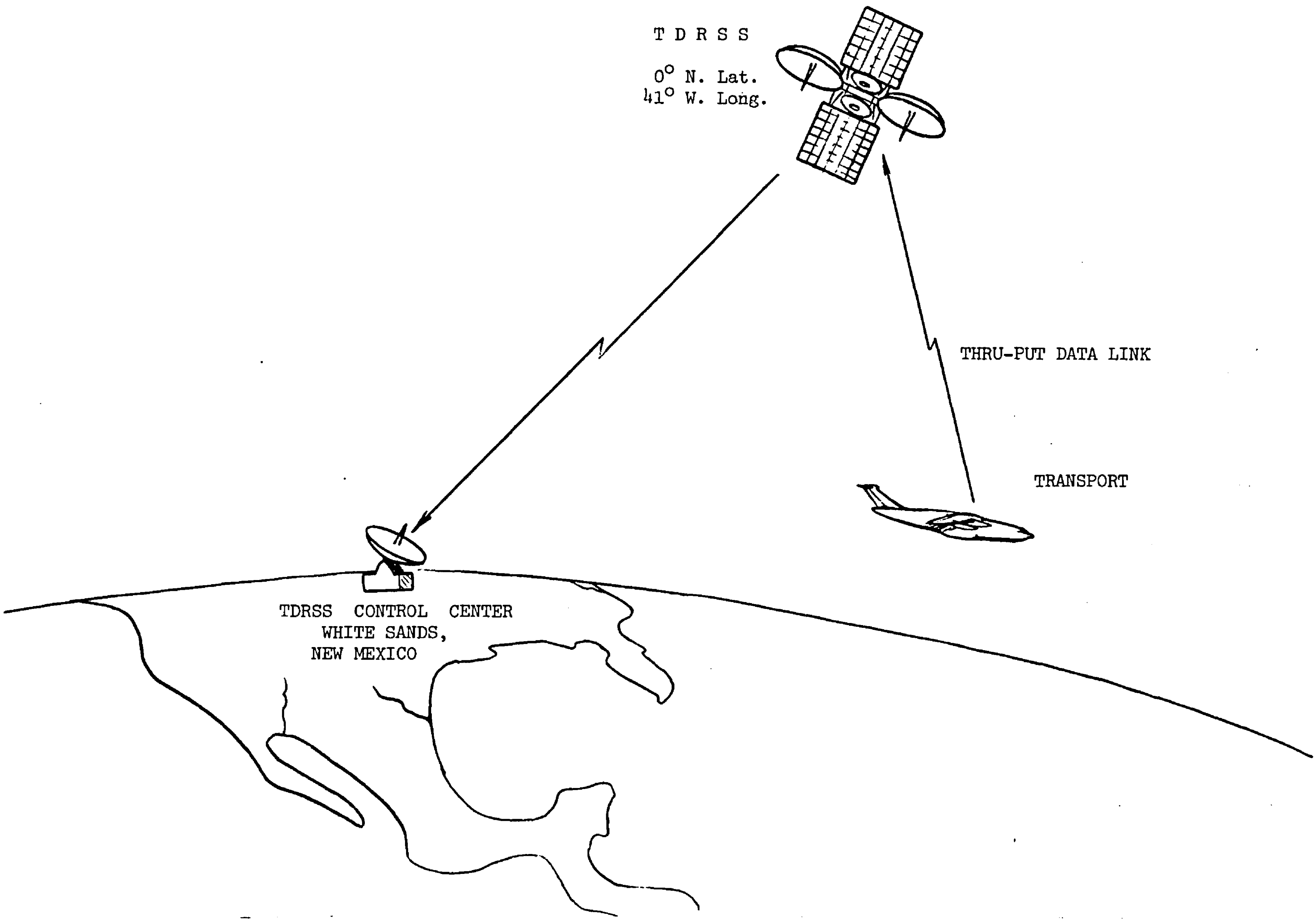


Figure 3.- TDRSS transport tracking method.

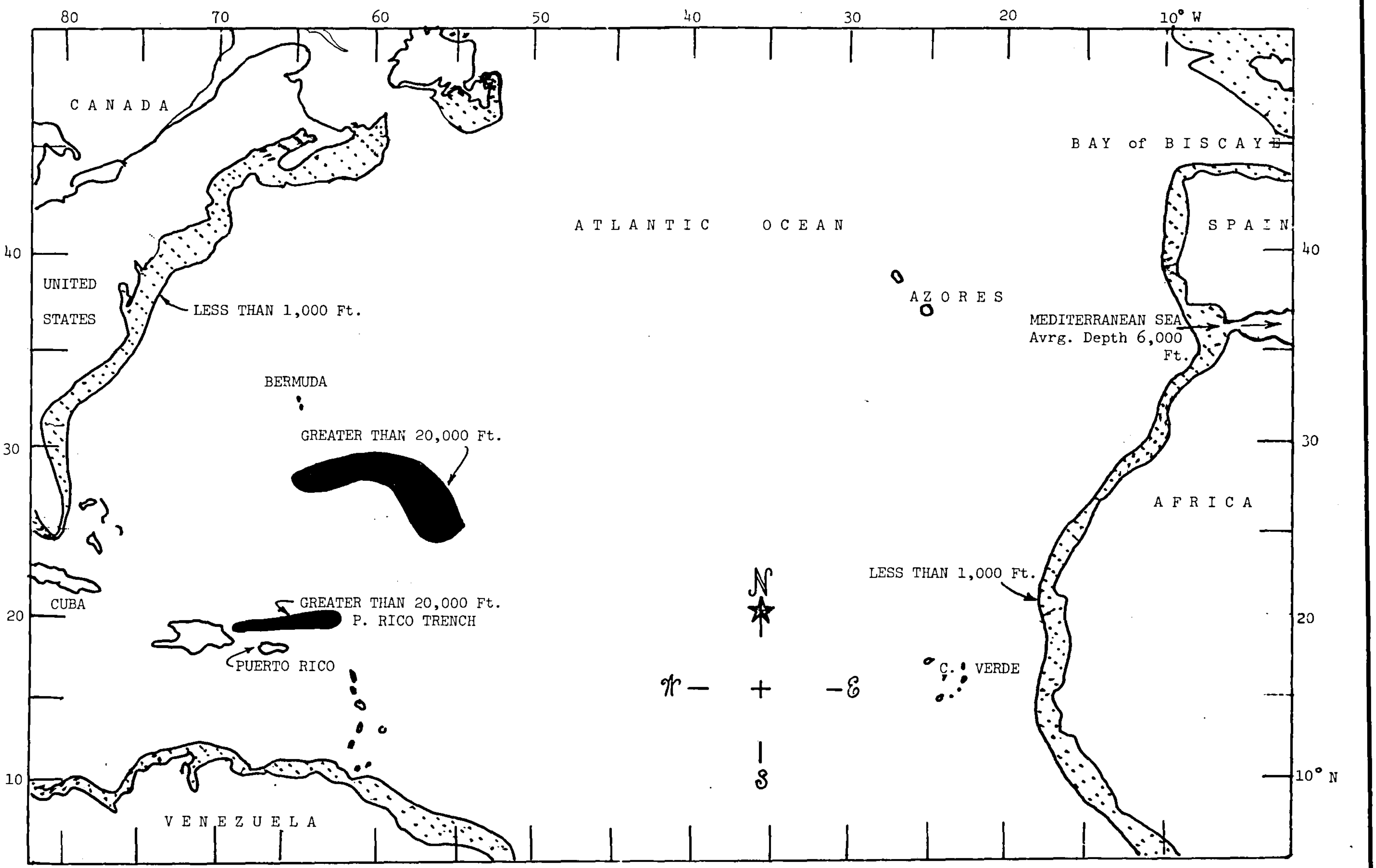


Figure 4.- North Atlantic Ocean--depth profile.

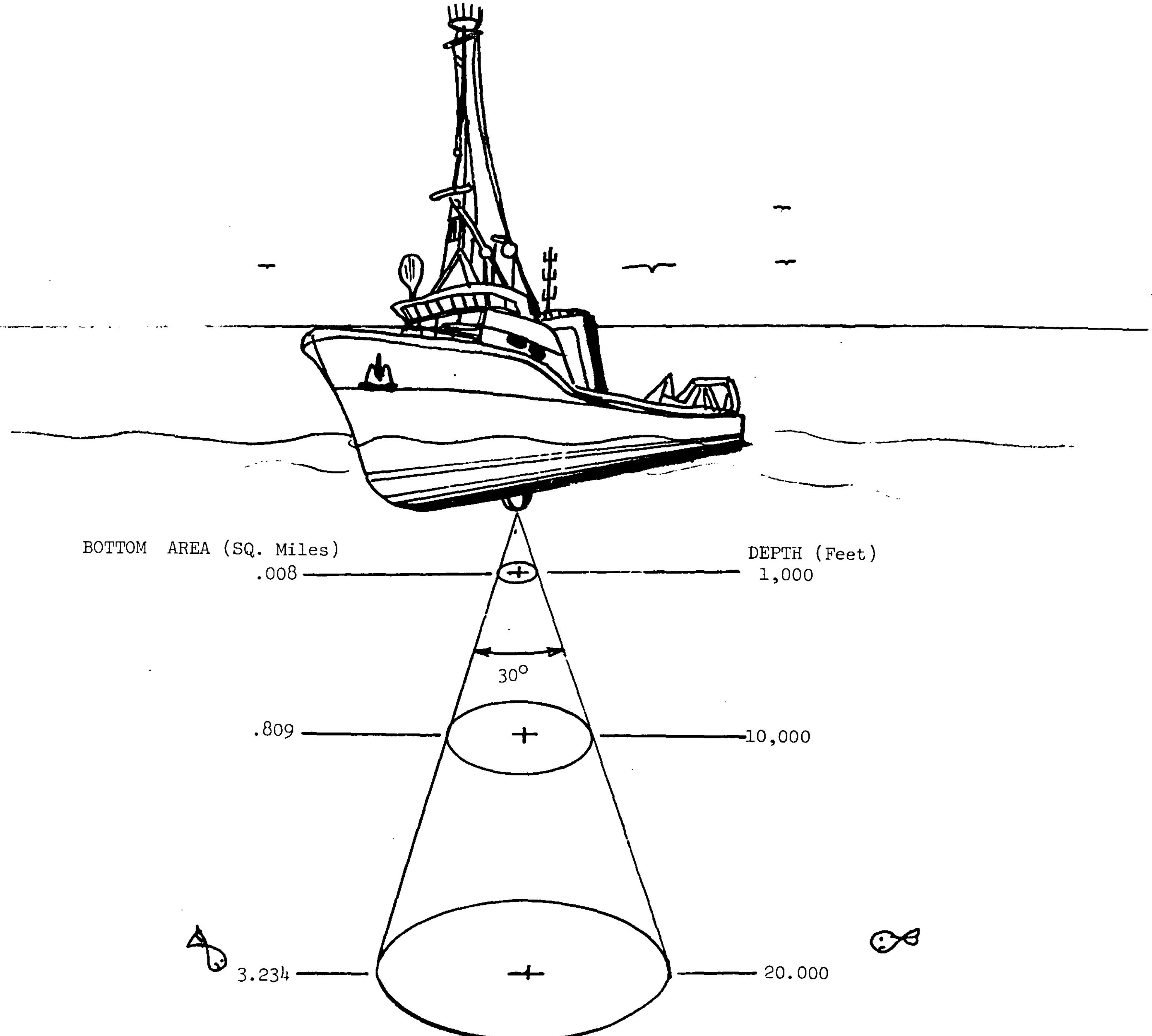


Figure 5.- Down-looking sonar, 30° beam.

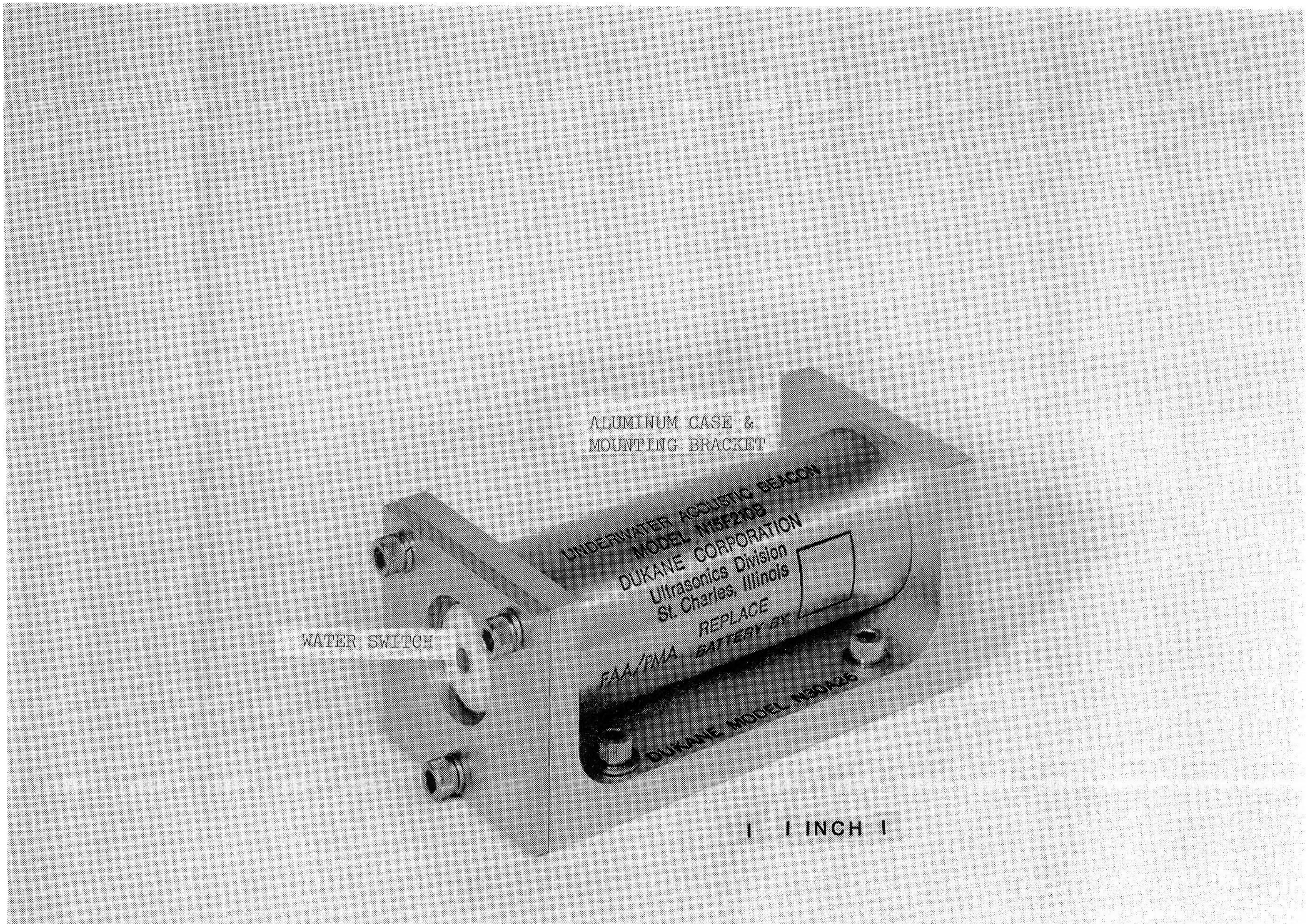


Figure 6.- Underwater sound source commercial aircraft FAA approved.

Figure 7.- Underwater sound source commercial aircraft FAA approved.

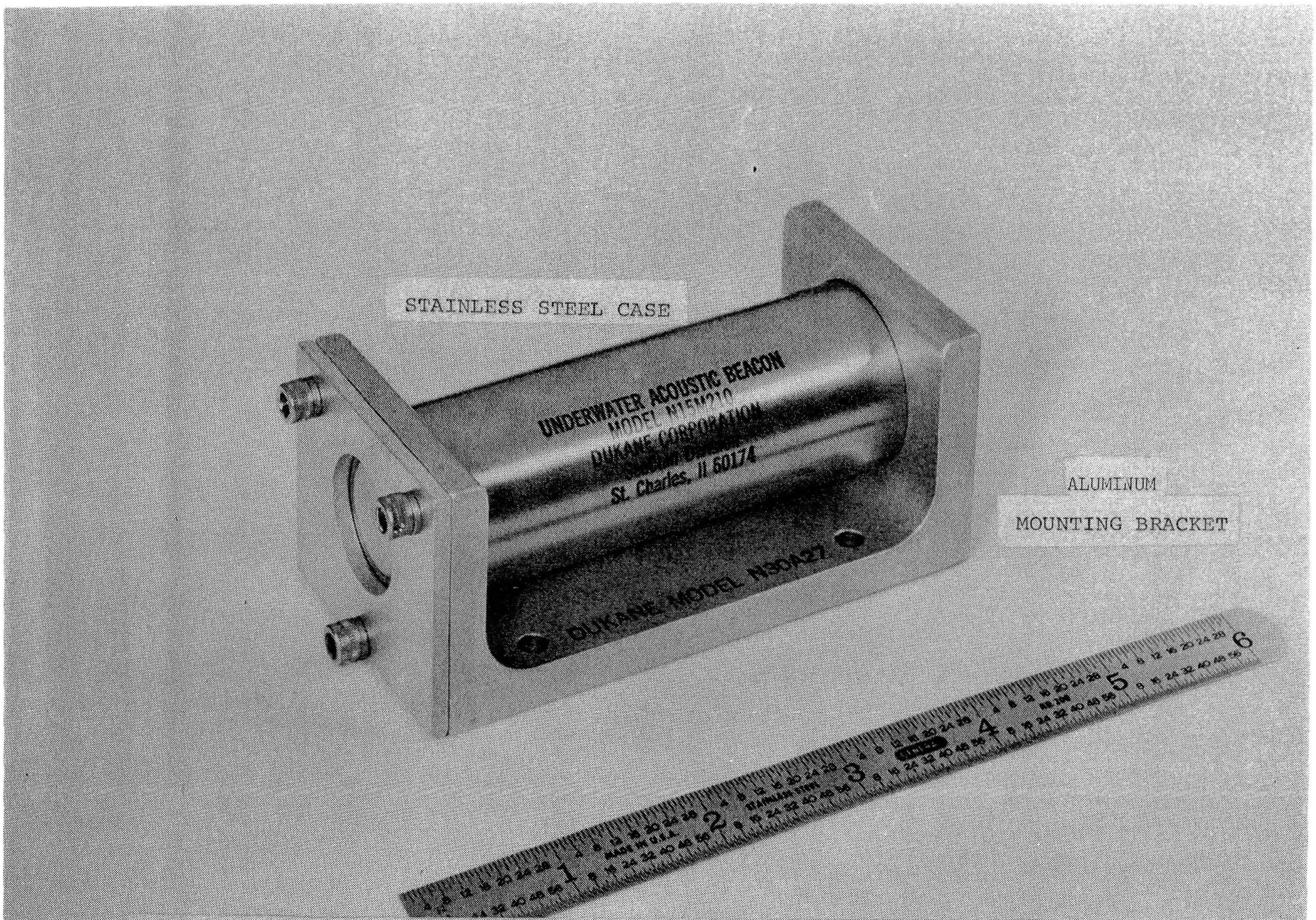


Figure 8.- Underwater recovery aid commercial version of naval weapons MK 87 Mod O shown with optional mounting.

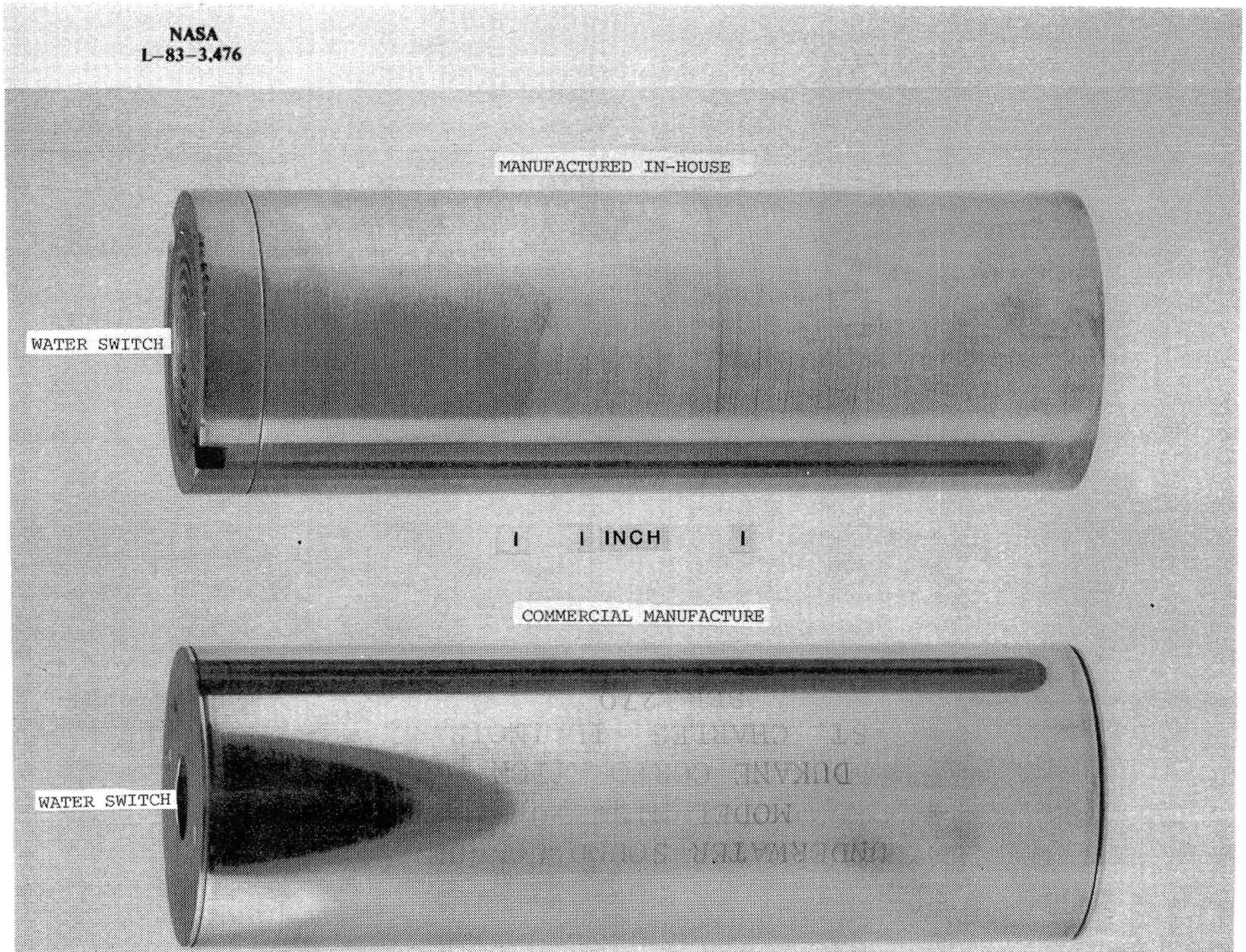


Figure 9.- Underwater recovery aids used on early NASA research payloads--stainless steel case.

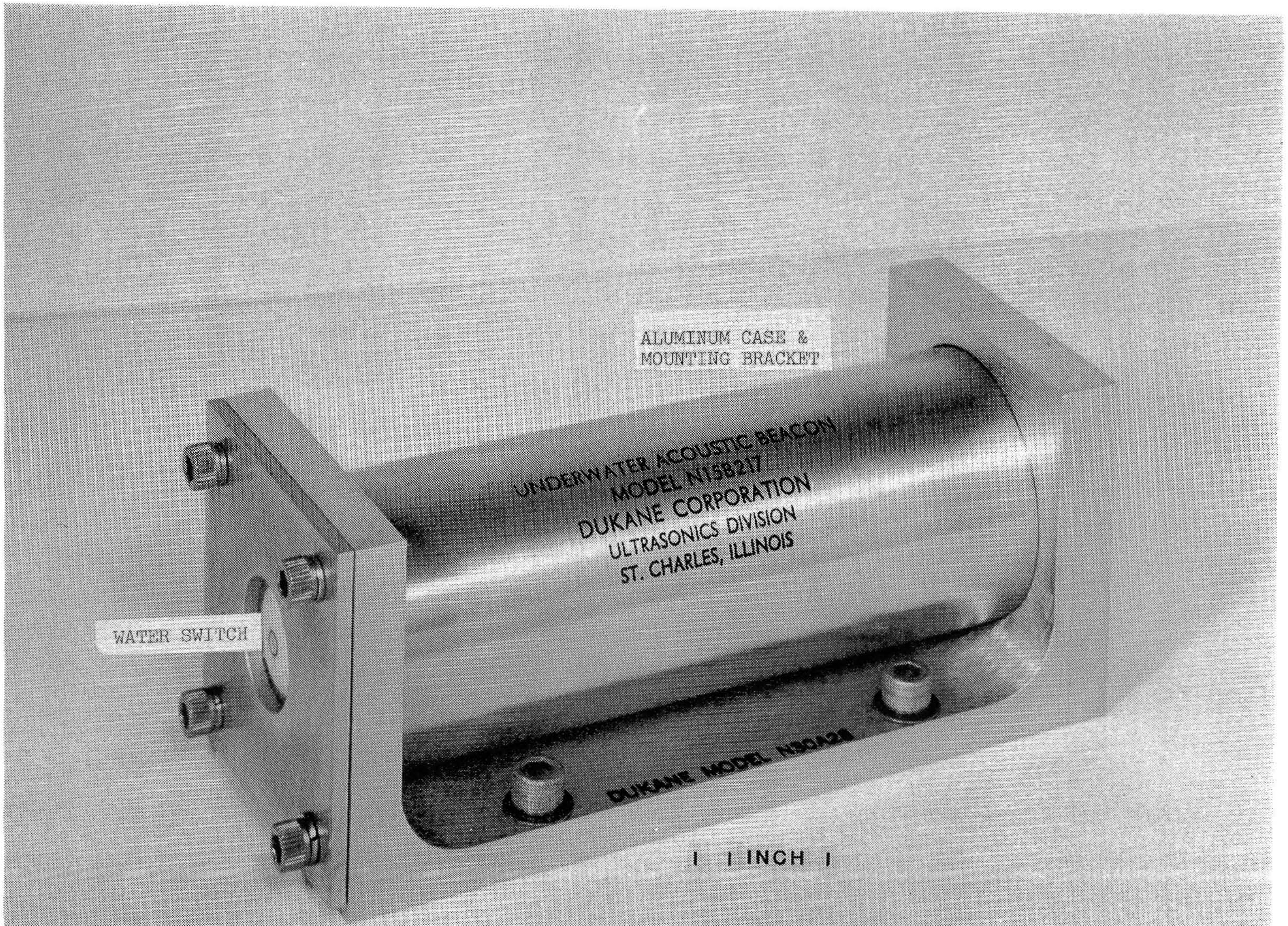


Figure 10.- Low frequency underwater location aids, long range acquisition, developed for Apollo spacecraft--aluminium case.

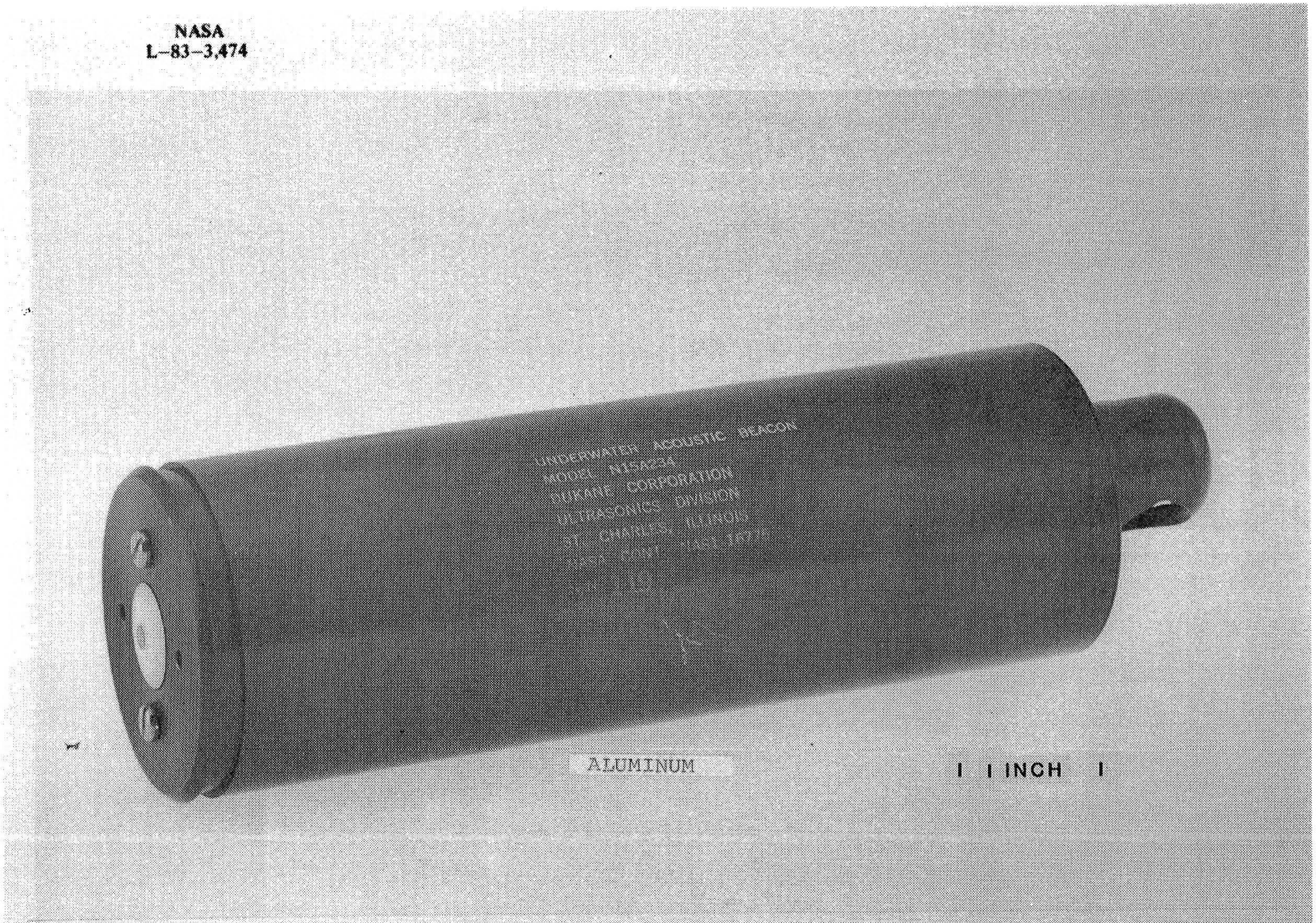


Figure 11.- Underwater location aid for use under severe environmental conditions on Space Shuttle.

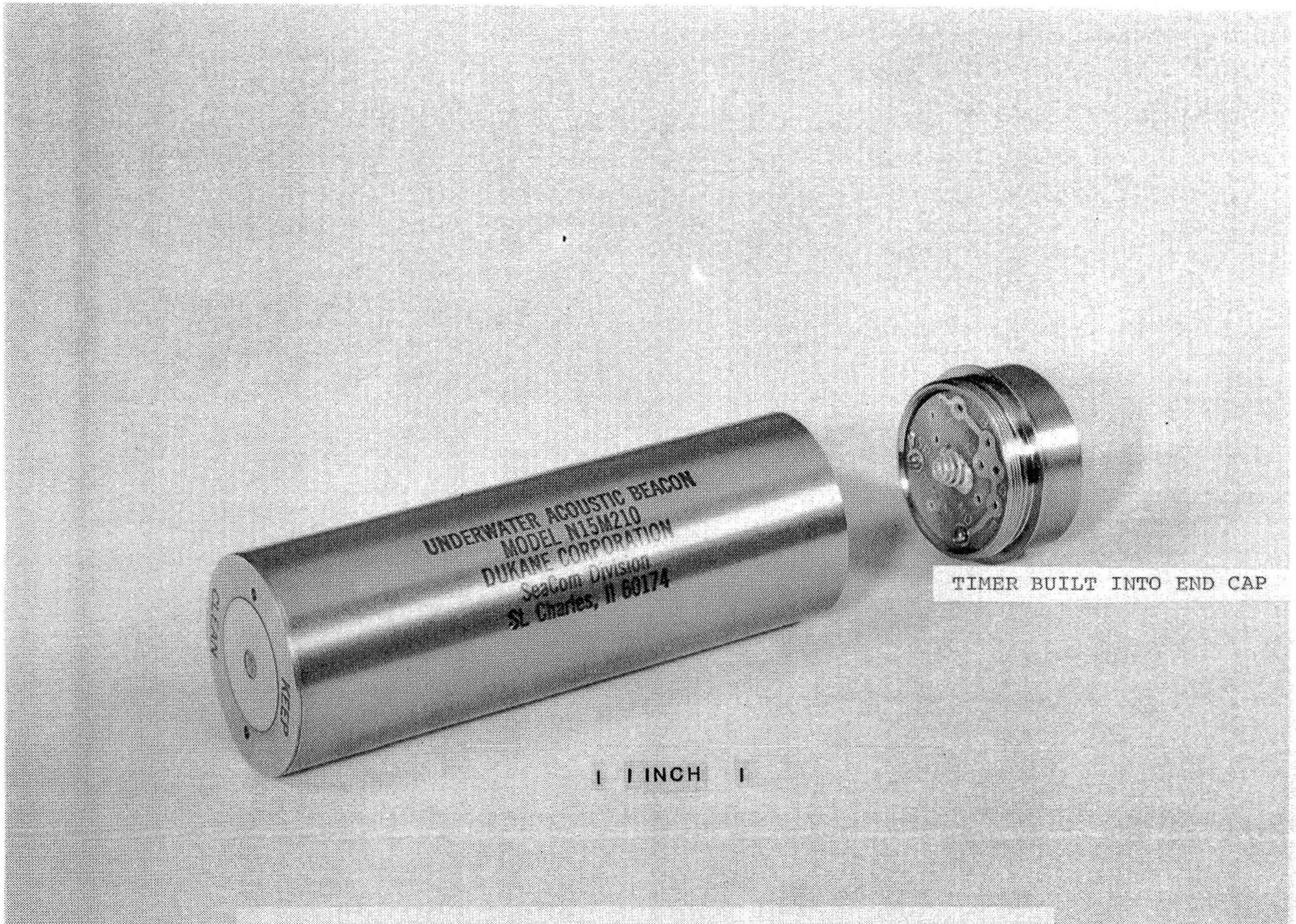


Figure 12.- Delayed turnon timing device designed for Navy MK 87 Mod 0.

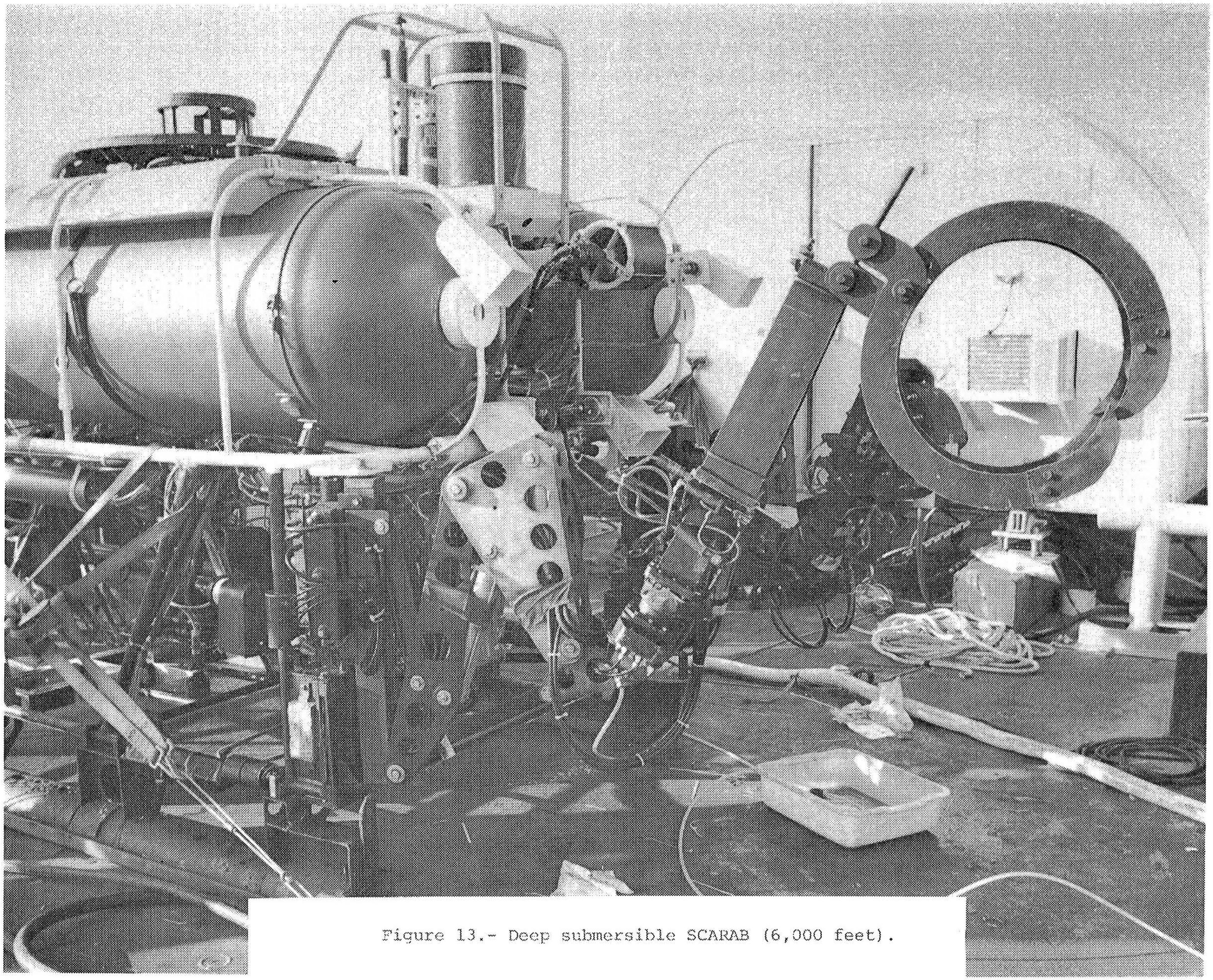


Figure 13.- Deep submersible SCARAB (6,000 feet).

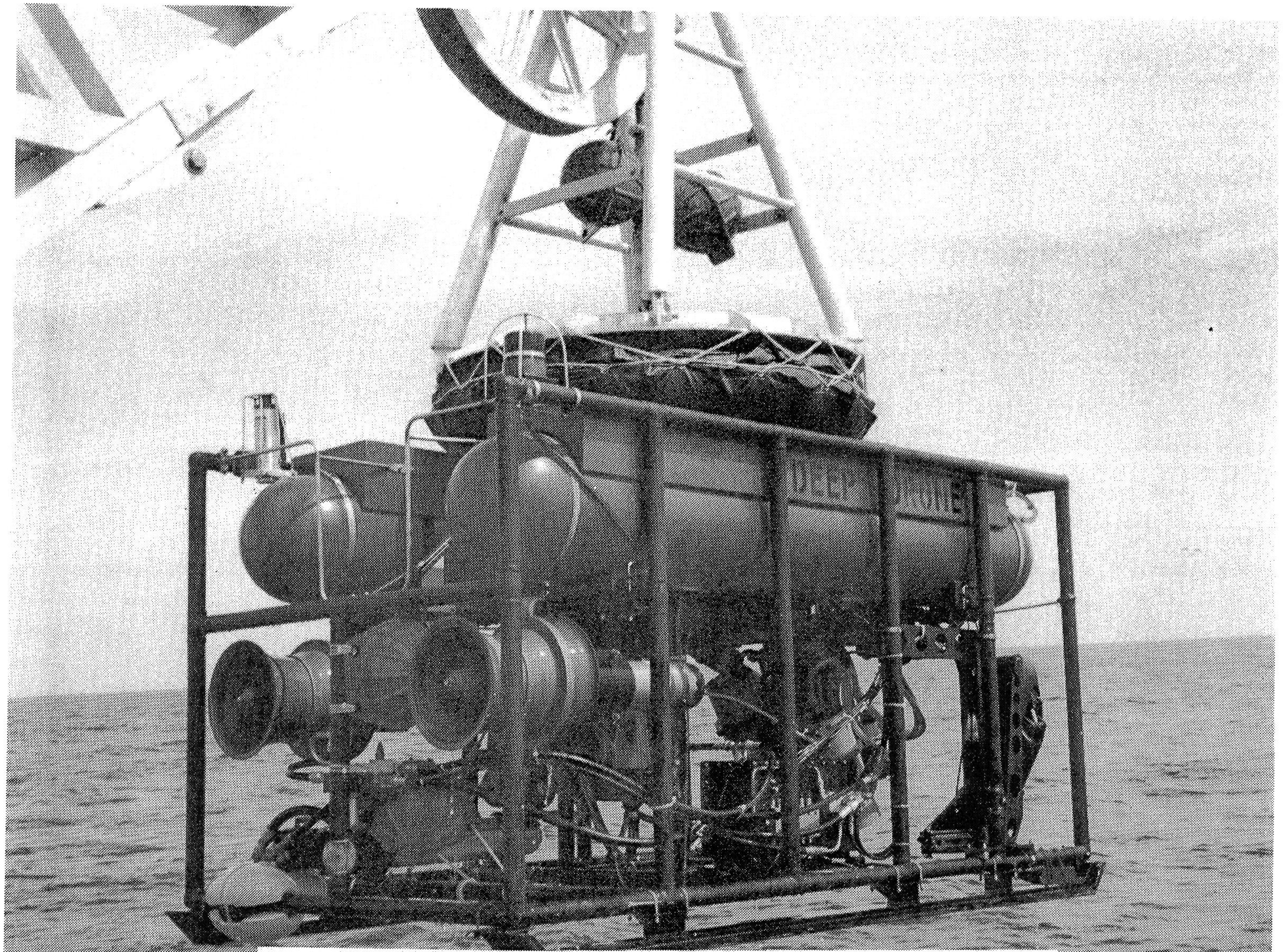


Figure 14.- Submersible deep drone operated by US Navy.

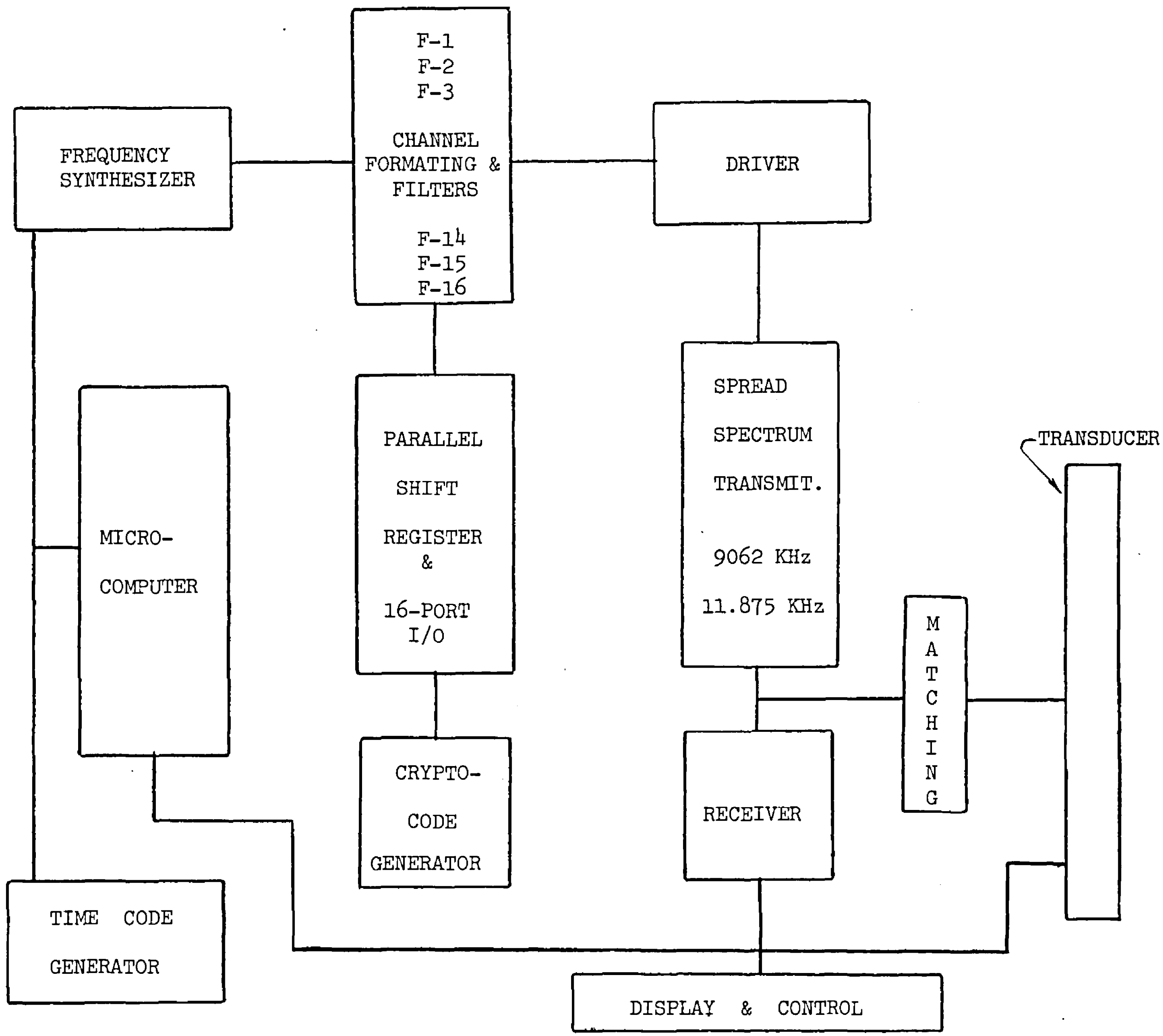


Figure 15.- Search transceiver/receiver.

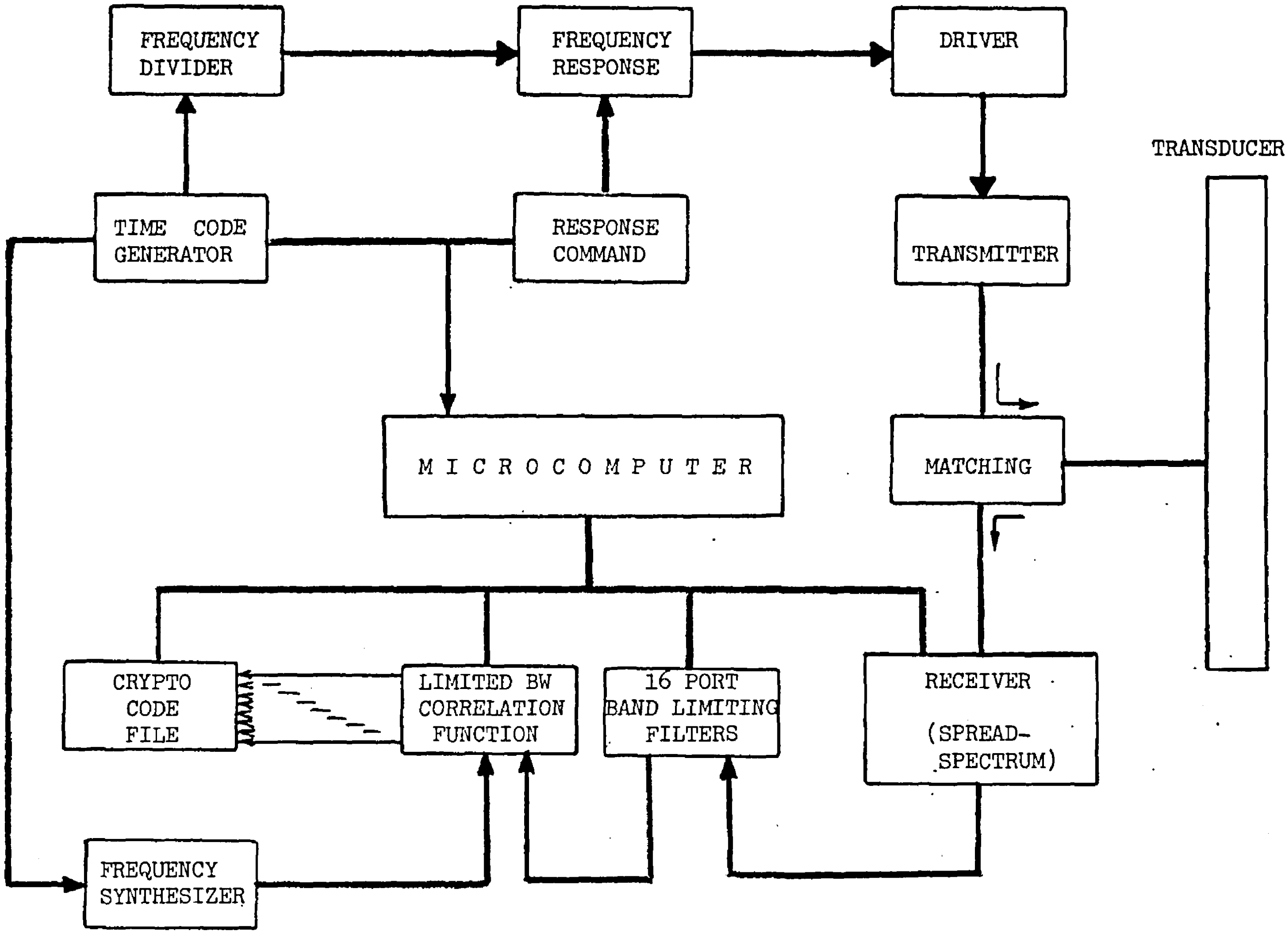


Figure 16.- Underwater transponder/transmitter.

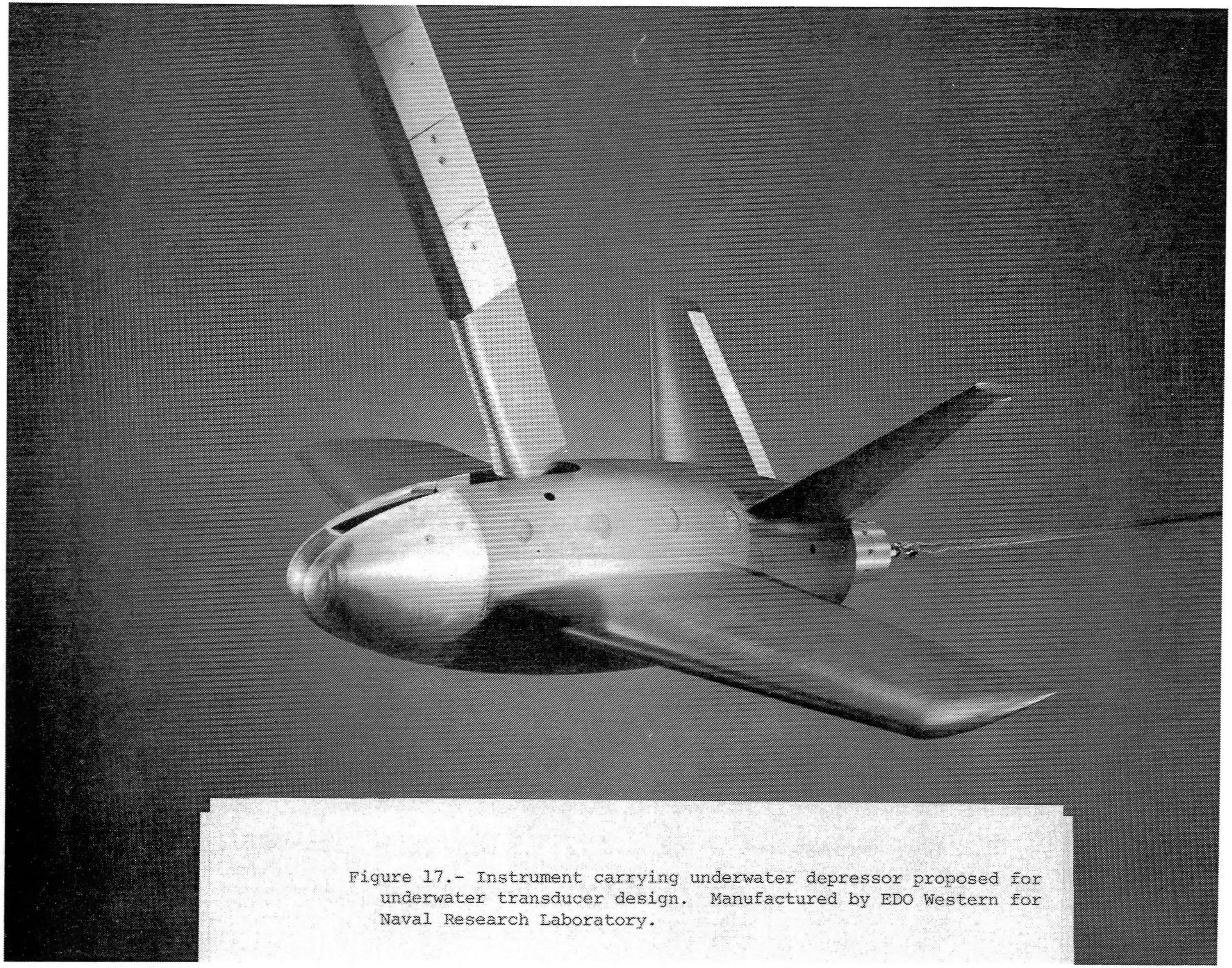


Figure 17.- Instrument carrying underwater depressor proposed for underwater transducer design. Manufactured by EDO Western for Naval Research Laboratory.

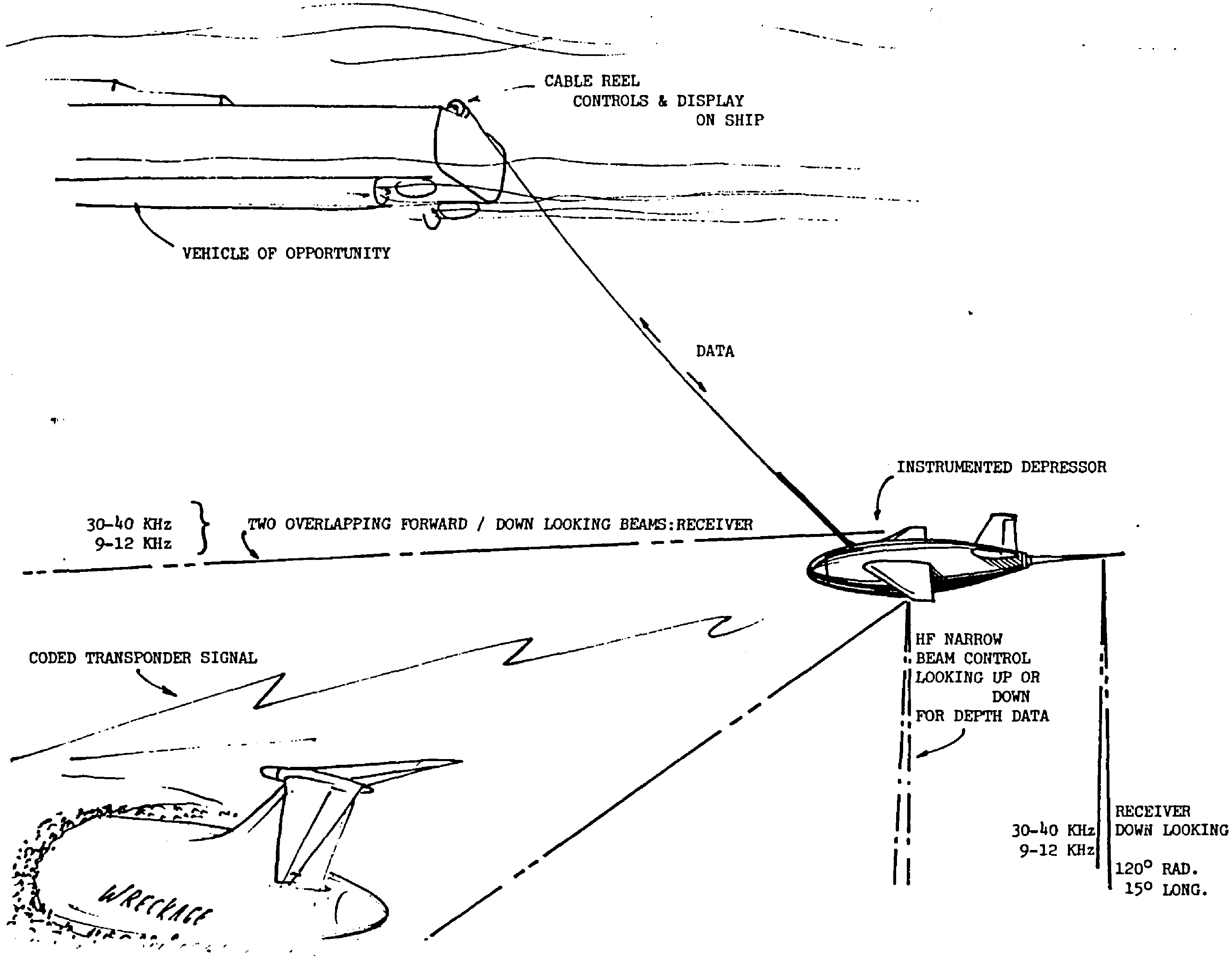
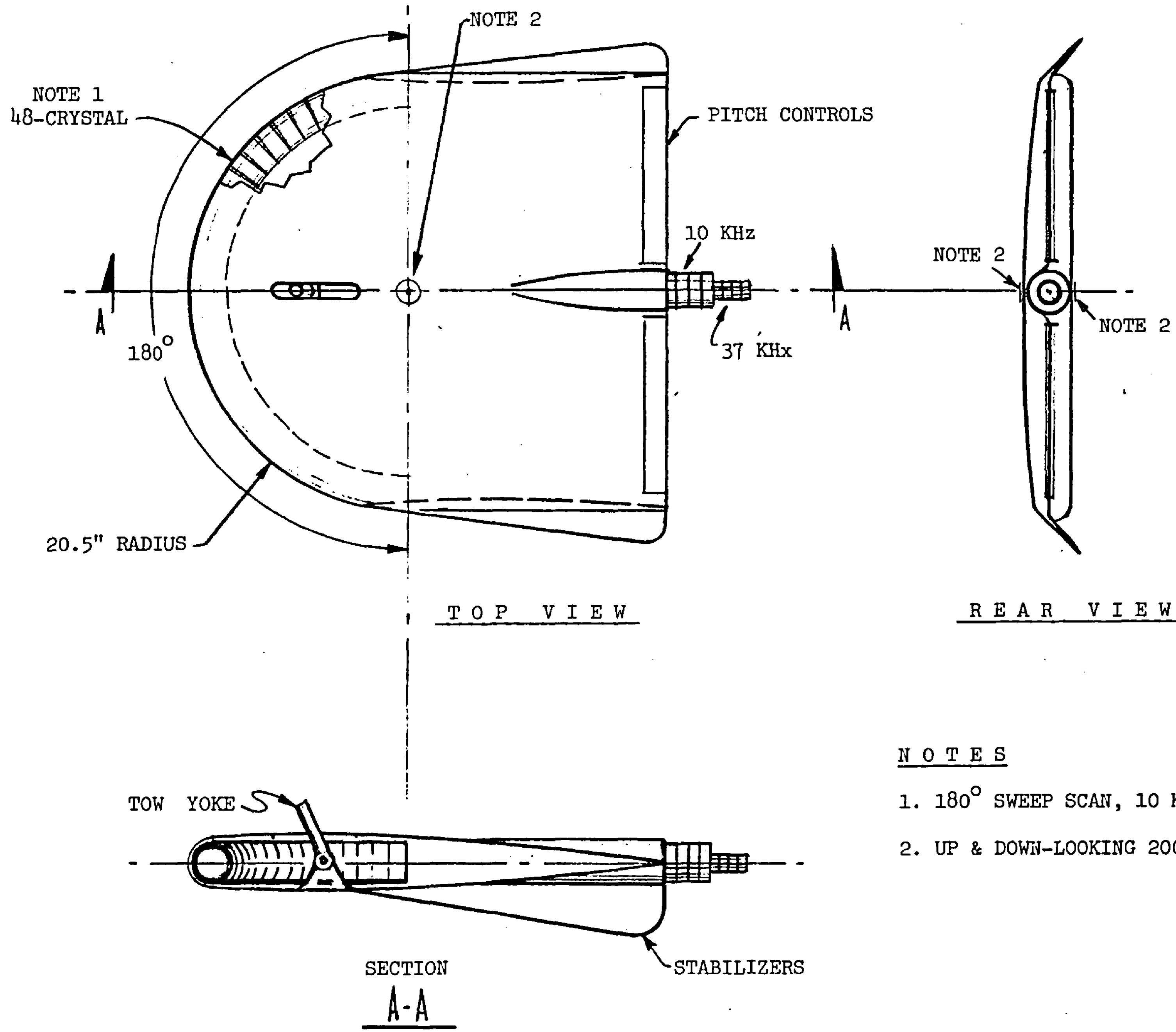


Figure 18.- Fixed beam, towed transducer platform using NRL type depressor.



N O T E S

1. 180° SWEEP SCAN, 10 KHz.

2. UP & DOWN-LOOKING 200 KHz DEPTH FINDER.

Figure 19.- Beam-forming electronic scan, towed transducer/hydrophone underwater platform.

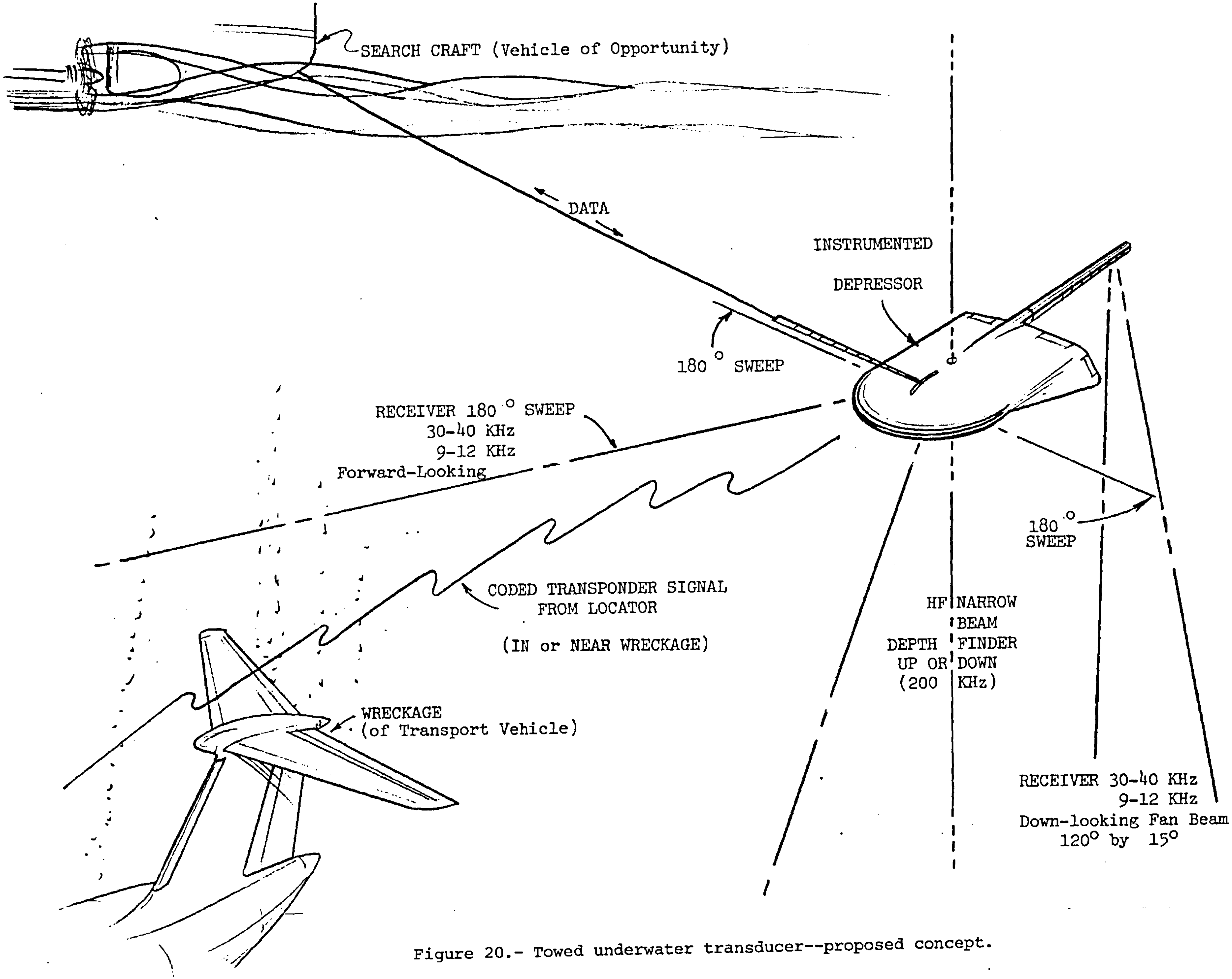


Figure 20.- Towed underwater transducer--proposed concept.

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15. Supplementary Notes

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16. Abstract

A study to provide the U.S. Air Force Weapons Laboratory with information related to the location of objects lost at sea is presented.

Acoustic devices attached to an object prior to being transported is recommended as a homing beacon. Minimum requirements and some environmental constraints have been defined. Methods and procedures for search and recovery are also discussed.

Both an "interim" system and a more "advanced" system are outlined. Controlled acoustic emission to enhance security is the theme followed.

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